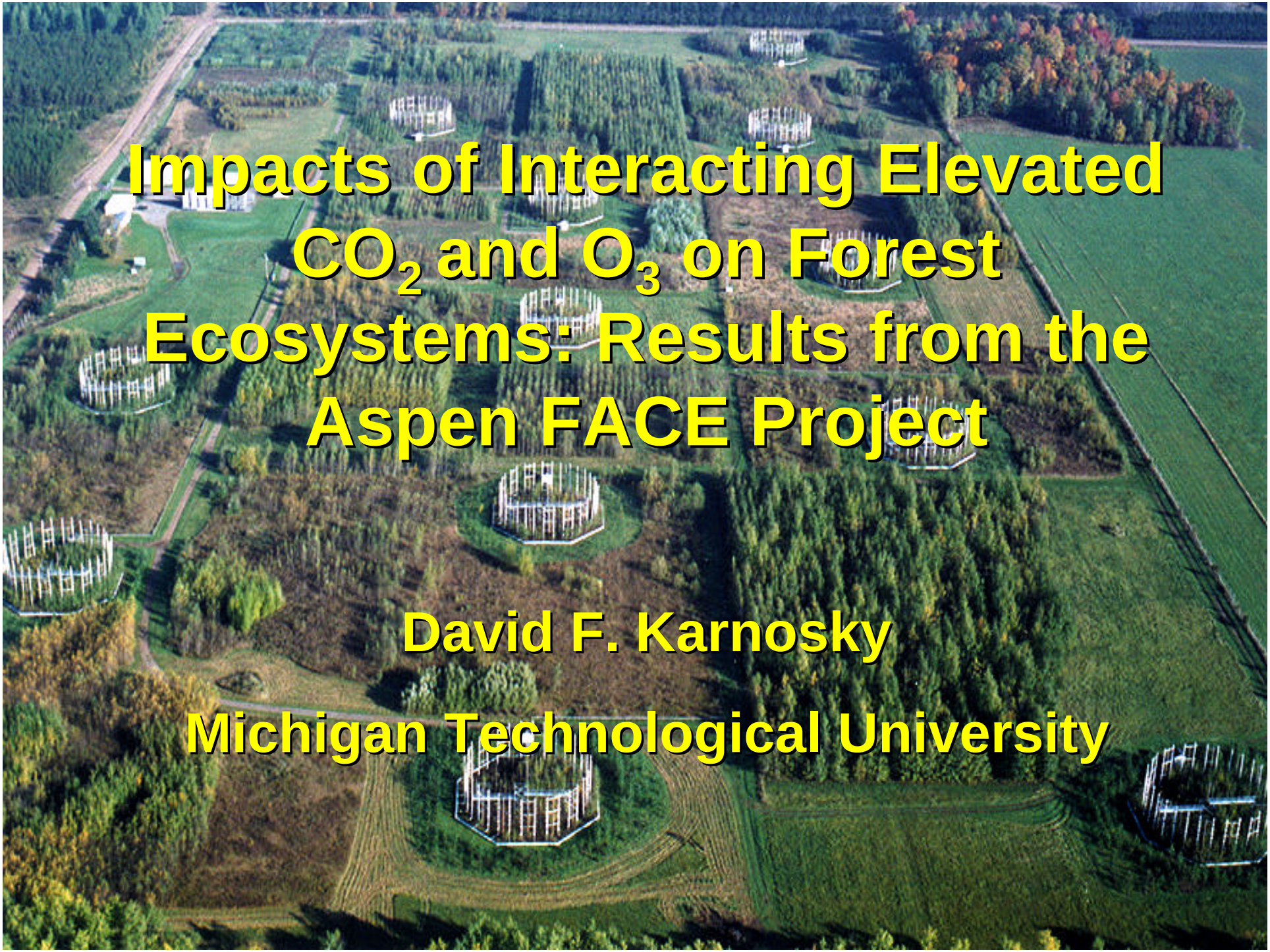
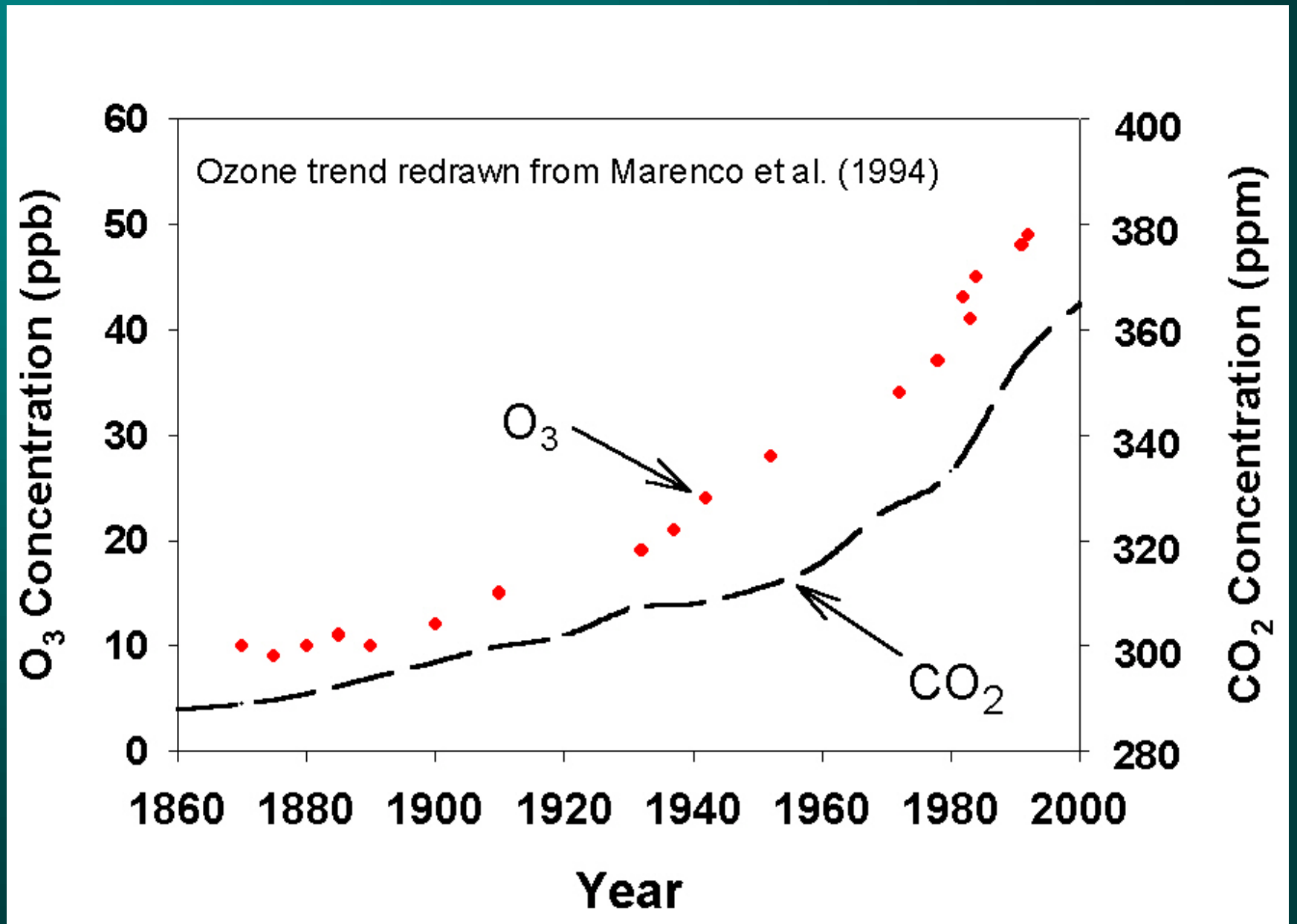


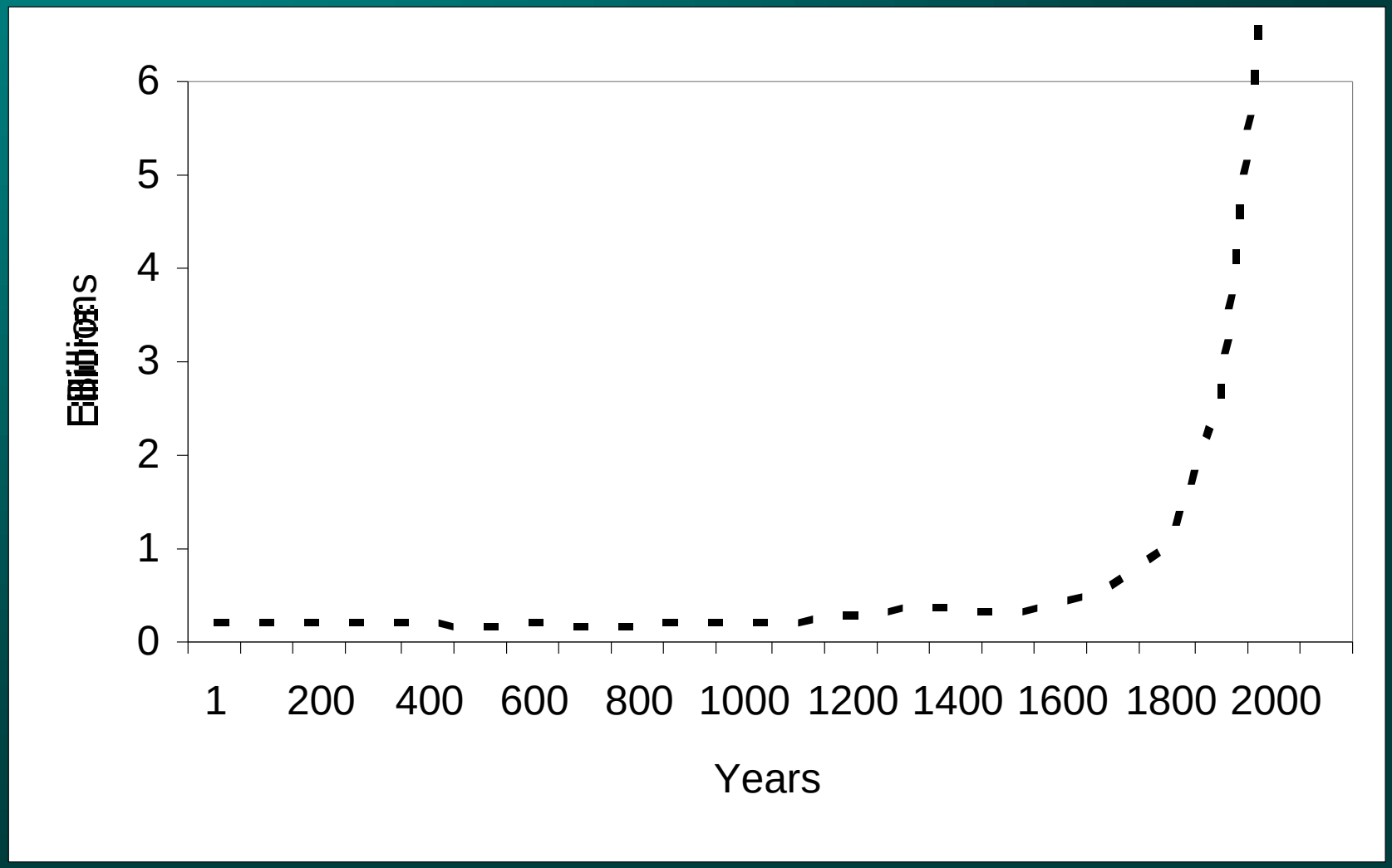
Impacts of Interacting Elevated CO_2 and O_3 on Forest Ecosystems: Results from the Aspen FACE Project

David F. Karnosky

Michigan Technological University


Ozone trend redrawn from Marenco et al. (1994)
O_3
CO_2
O_3 Concentration (ppb)
CO_2 Concentration (ppm)
Year
0
10
20
30
40
50
60
280
300
320
340
360
380
400
1860
1880
1900
1920
1940
1960
1980
2000

Global Population from Year 1 to Year 2000



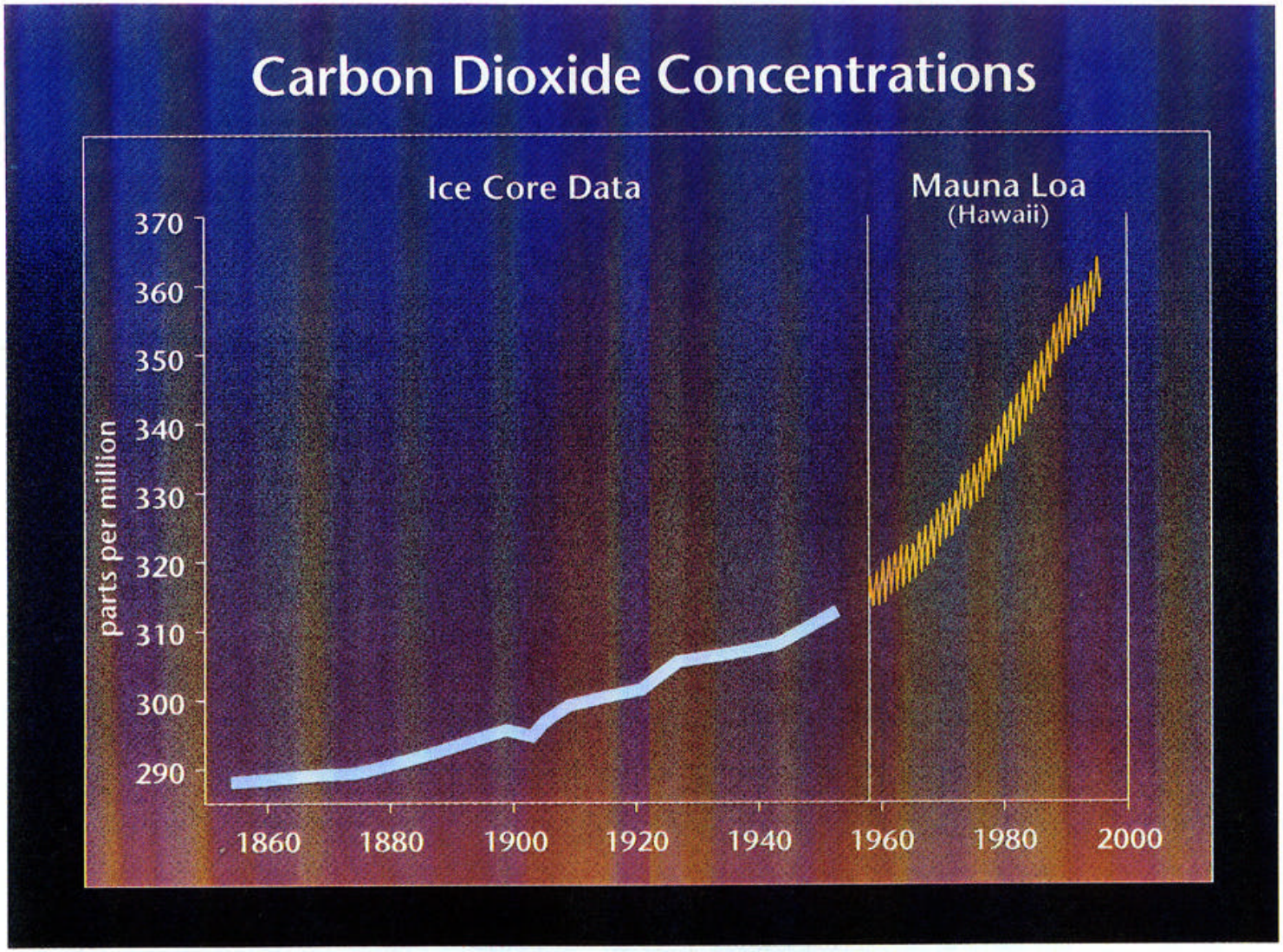
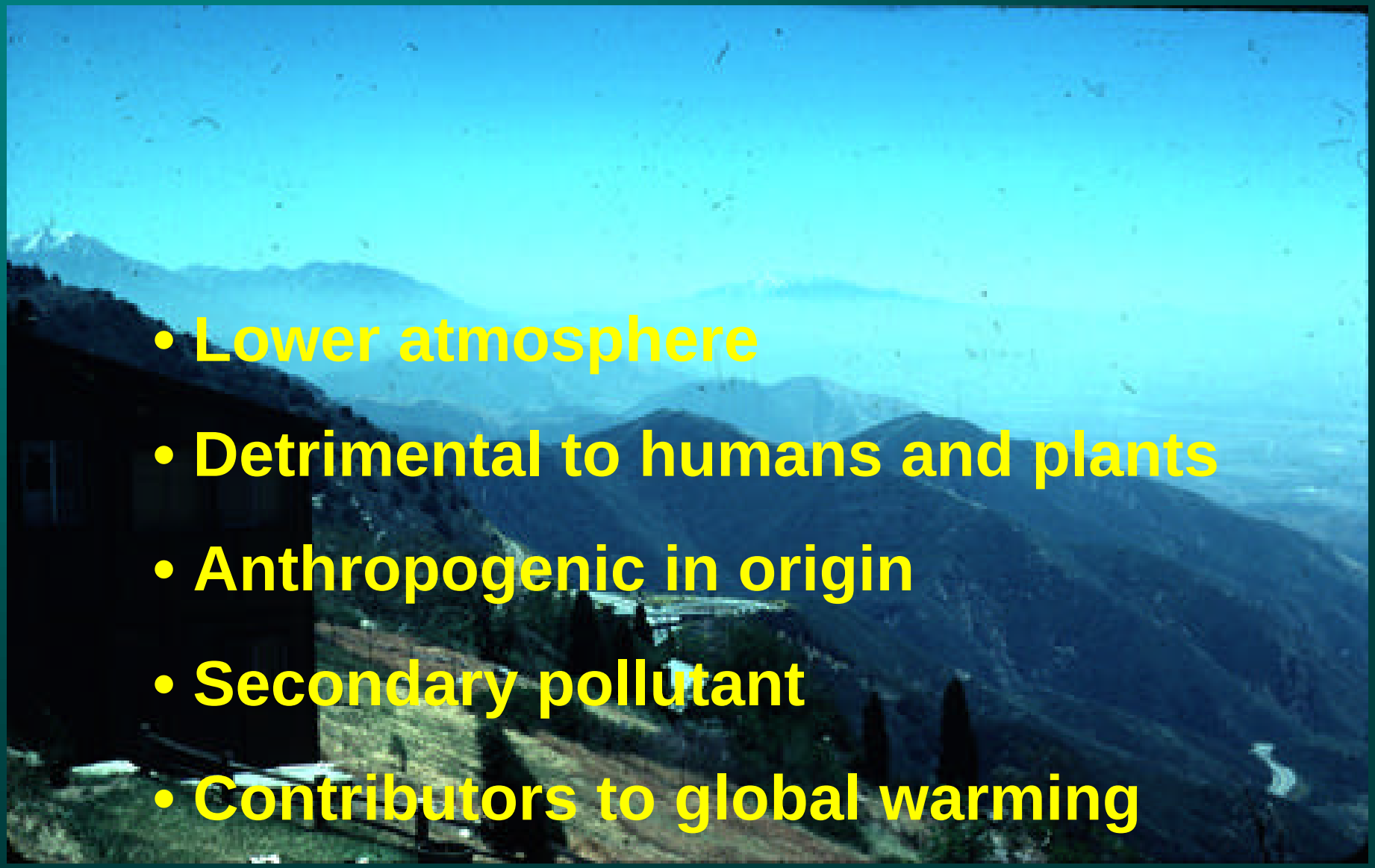


Figure 4. Since the beginning of the Industrial Revolution in the middle of the 19th century, the concentration of carbon dioxide (CO_2) in the atmosphere has steadily increased. Beginning in 1957, continual measurements of atmospheric CO_2 concentrations have been made by scientists at an observatory in Mauna Loa, Hawaii. The seasonal cycle of vegetation in Northern latitudes can be seen in this record: each spring the vegetation "inhales" and absorbs CO_2, and each autumn most of that CO_2 is released back to the atmosphere.

Stratospheric Ozone

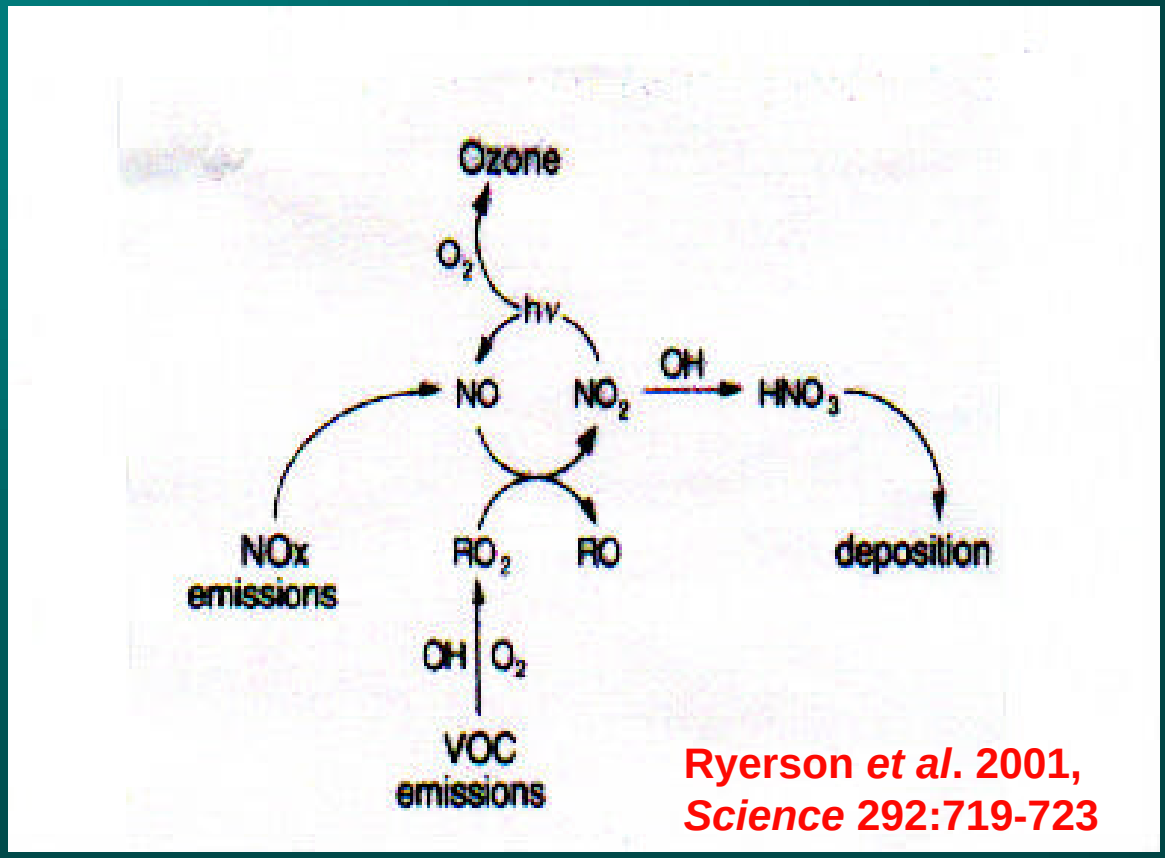
- Upper atmosphere
- Beneficial (UV-B shield)

Tropospheric Ozone



- Lower atmosphere
- Detrimental to humans and plants
- Anthropogenic in origin
- Secondary pollutant
- Contributors to global warming

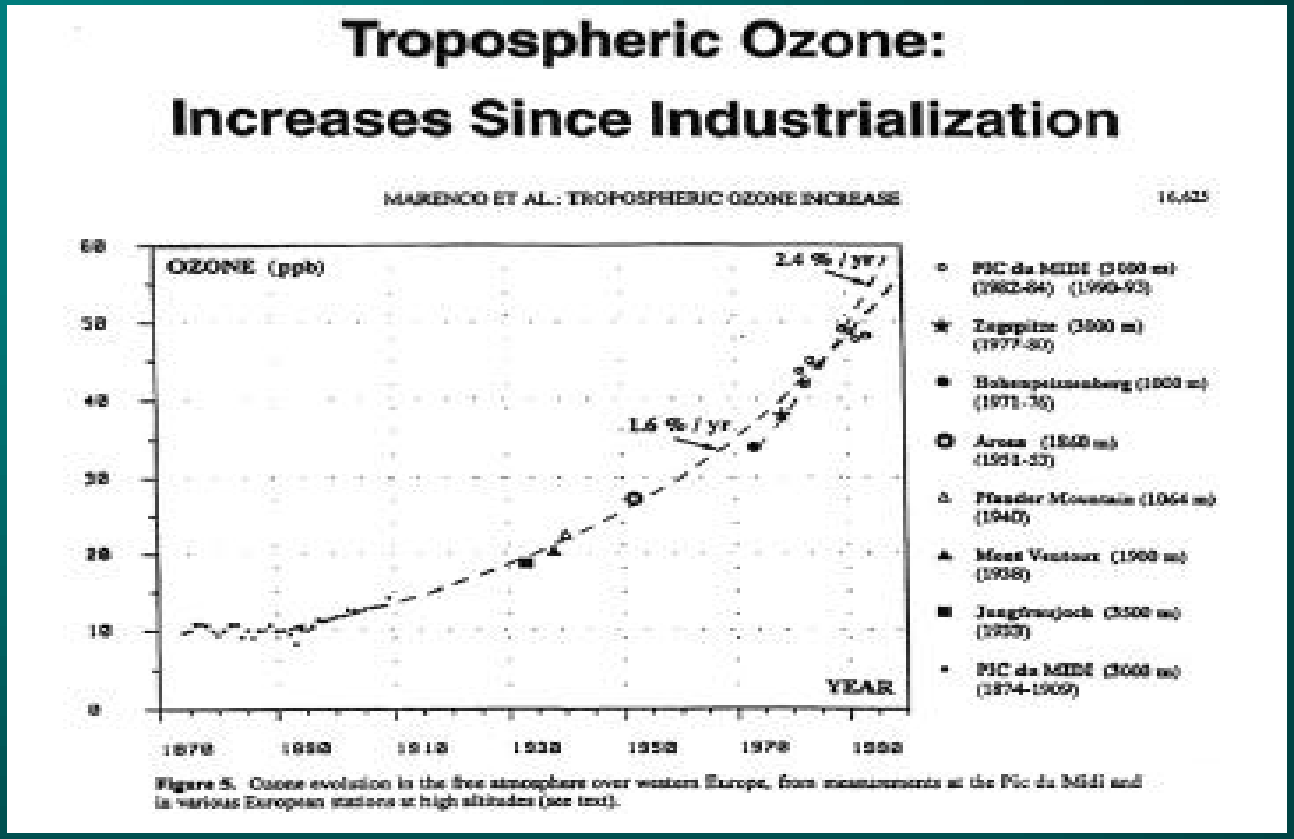
Tropospheric Ozone



Ryerson *et al*. 2001, *Science* 292:719-723

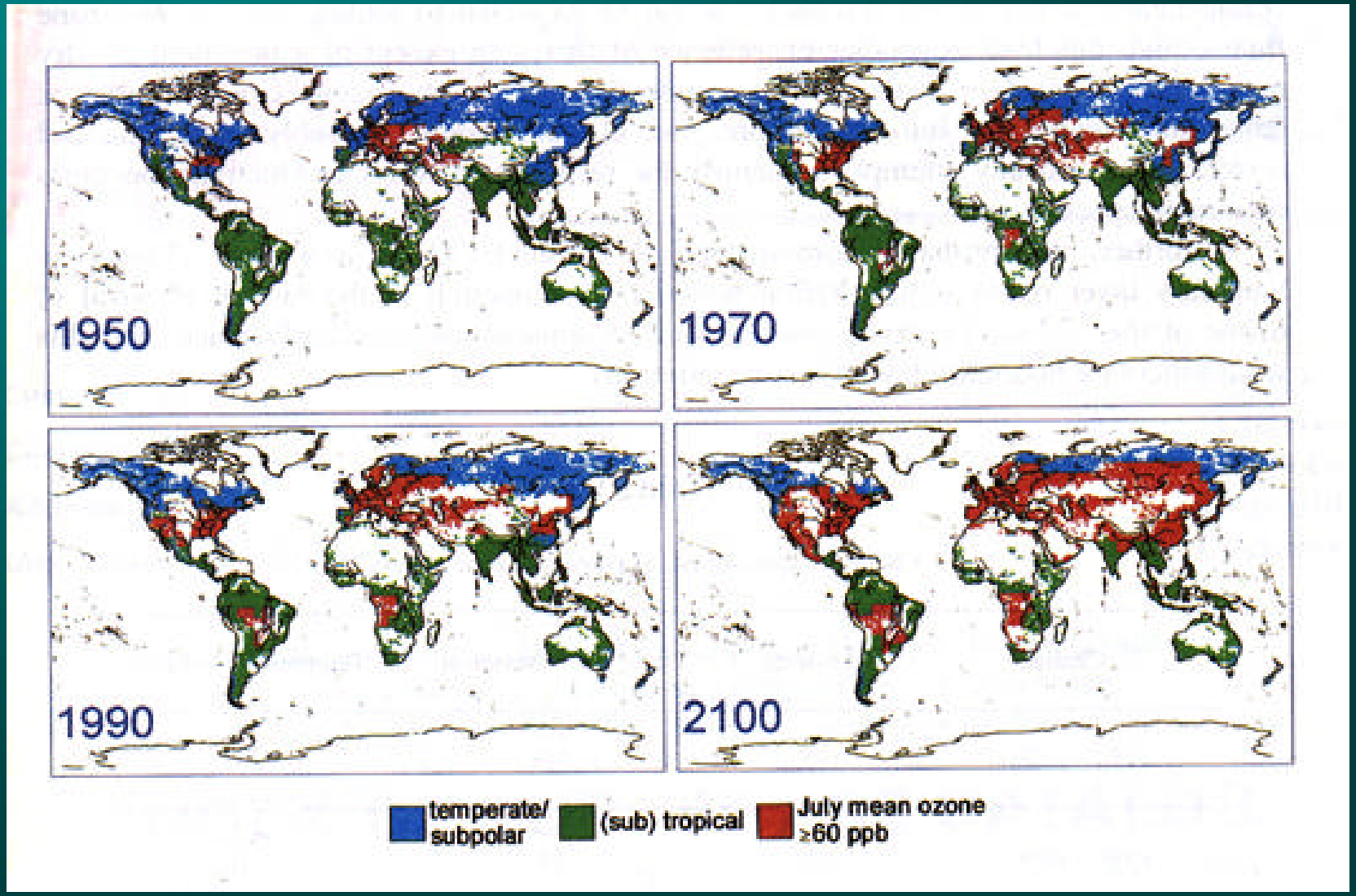
- Ozone photochemistry is driven by VOC precursors and anthropogenic NO_x
- NO_x emissions are largely related to vehicular traffic and fossil fuel burning

What are the Trends in O_3 Occurrence?



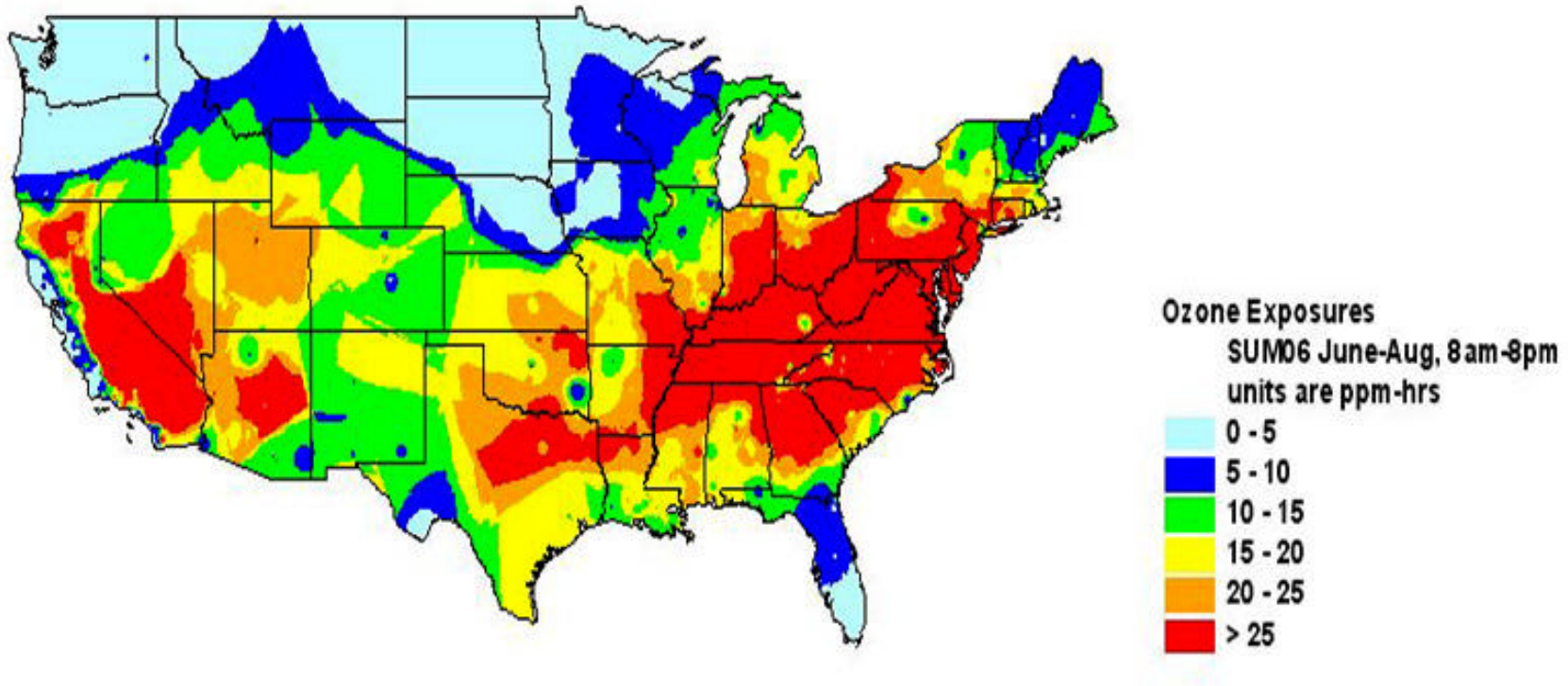
- Increasing 1-1/2 to 2% per year
  - Marenco *et al*. 1994, *J. Geophys. Res*. 99 (D8):16617-16632
- Increased 40% since preindustrial times (IPCC, 2001).

Ozone and Forests: Worldwide



From: Fowler *et al*. 1999, *Water, Air and Soil Pollut*. 116:5-32

Ozone and Forests: United States



- **Decreased peaks around metropolitan areas**
- **Increases still being measured in many rural areas**

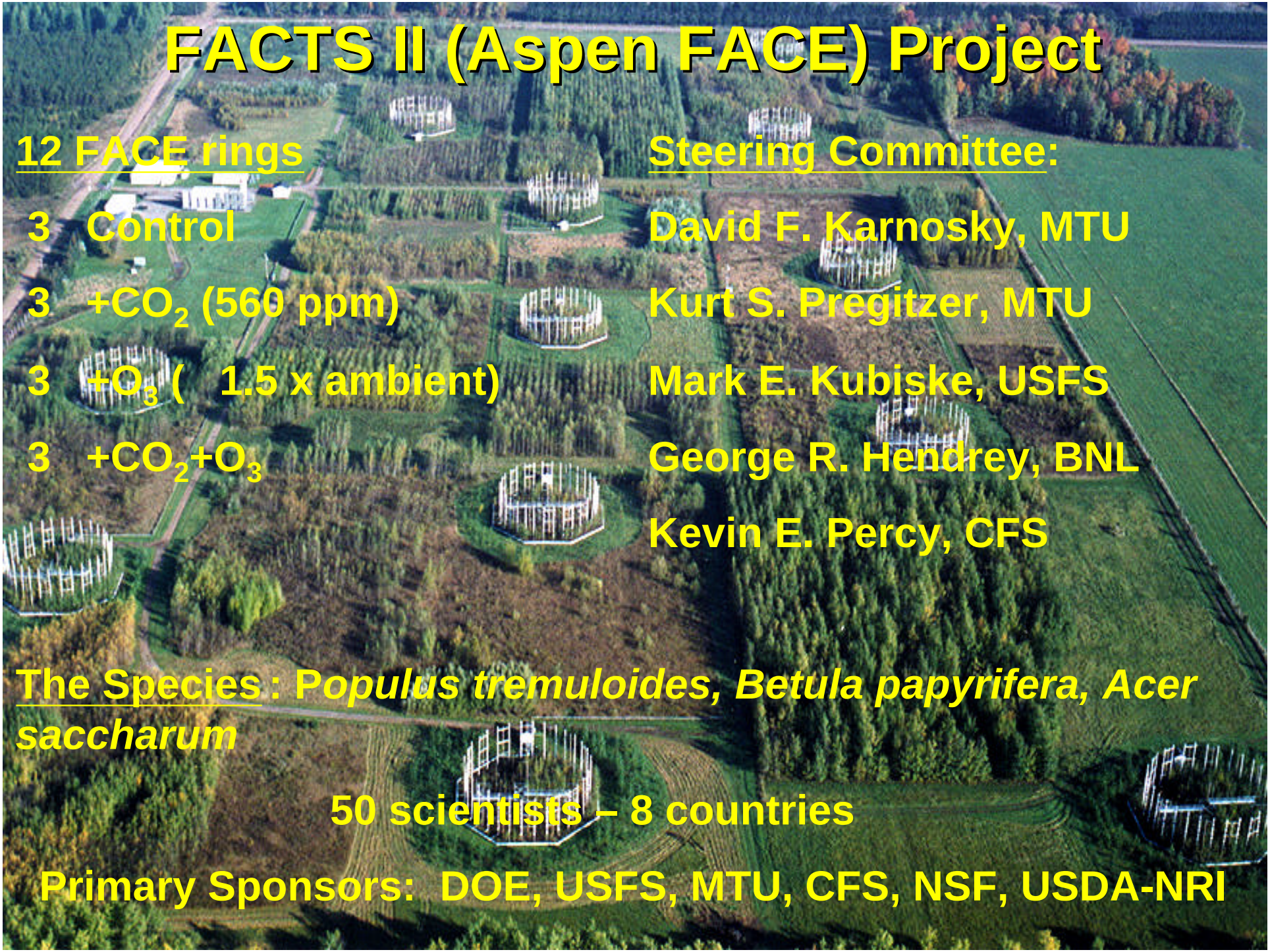
Data from: U.S. EPA O_3 data (website: http://www.epa.gov/airs/)

FACTS II (Aspen FACE) Objectives

- The main objective is to examine the effects of elevated CO_2 and/or O_3 on carbon and nitrogen cycles and on ecological interactions of a northern forest ecosystem.
  - carbon sequestration
  - growth and productivity
  - competitive interactions and stand dynamics
  - trophic interactions
  - foliar decomposition
  - mineral weathering
  - nutrient cycling
  - water balance

Policy Questions Addressed by FACE

- Are forests net carbon sources or sinks?
- Is carbon sequestered by trees stored for a long time in the soil?
- Will more or less CO_2 be sequestered by forests as CO_2 levels rise?
- Will forests become more or less productive over time under increasing CO_2?
- Will CO_2 “fertilization” be limited by rising O_3 levels, nitrogen limitation or drought?
- How will increasing CO_2 affect insect and disease interactions with forests?



FACTS II (Aspen FACE) Project

12 FACE rings

- 3 Control
- 3 +CO_2 (560 ppm)
- 3 +O_3 (1.5 x ambient)
- 3 +CO_2+O_3

Steering Committee:

David F. Karnosky, MTU

Kurt S. Pregitzer, MTU

Mark E. Kubiske, USFS

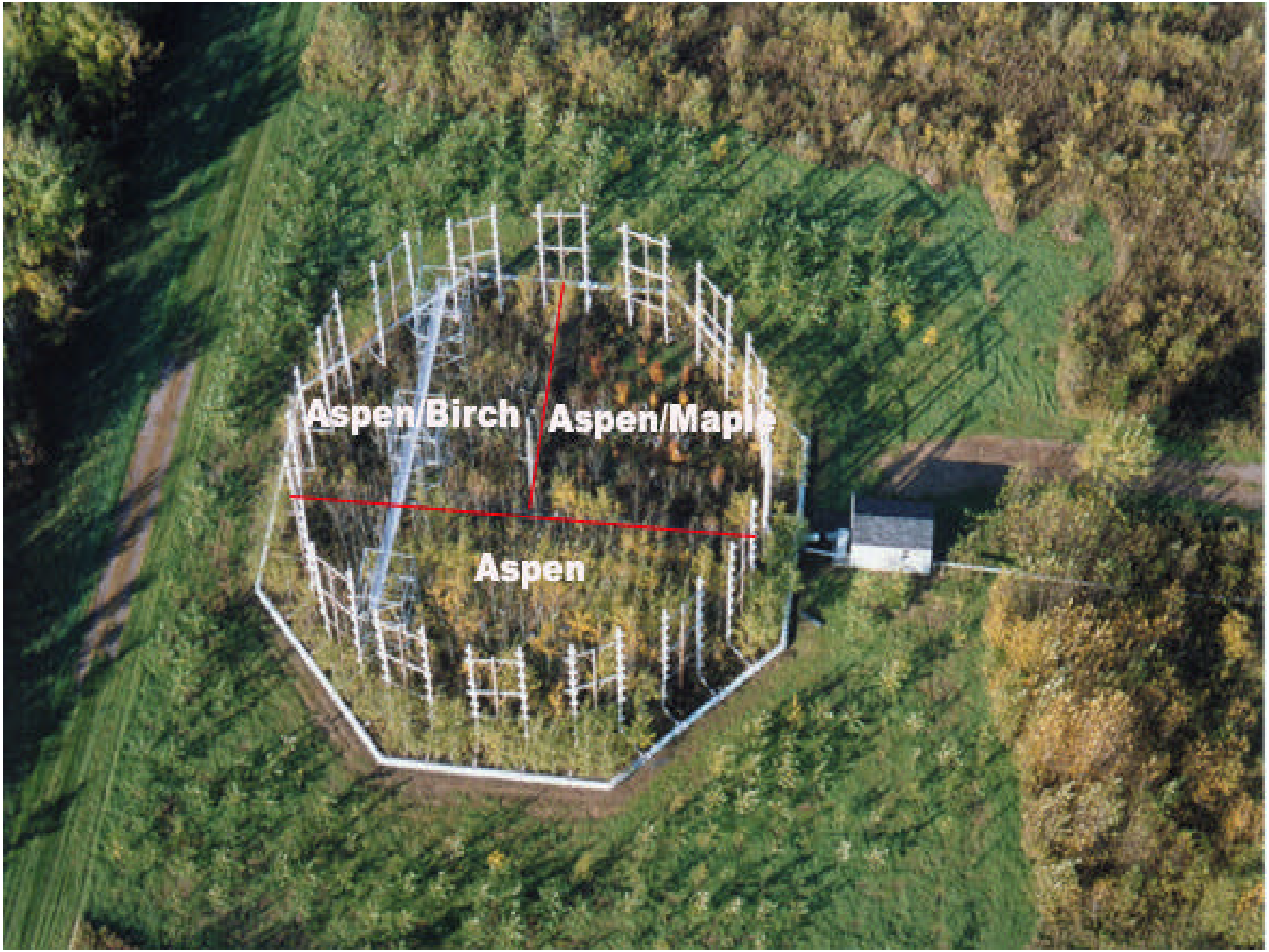
George R. Hendrey, BNL

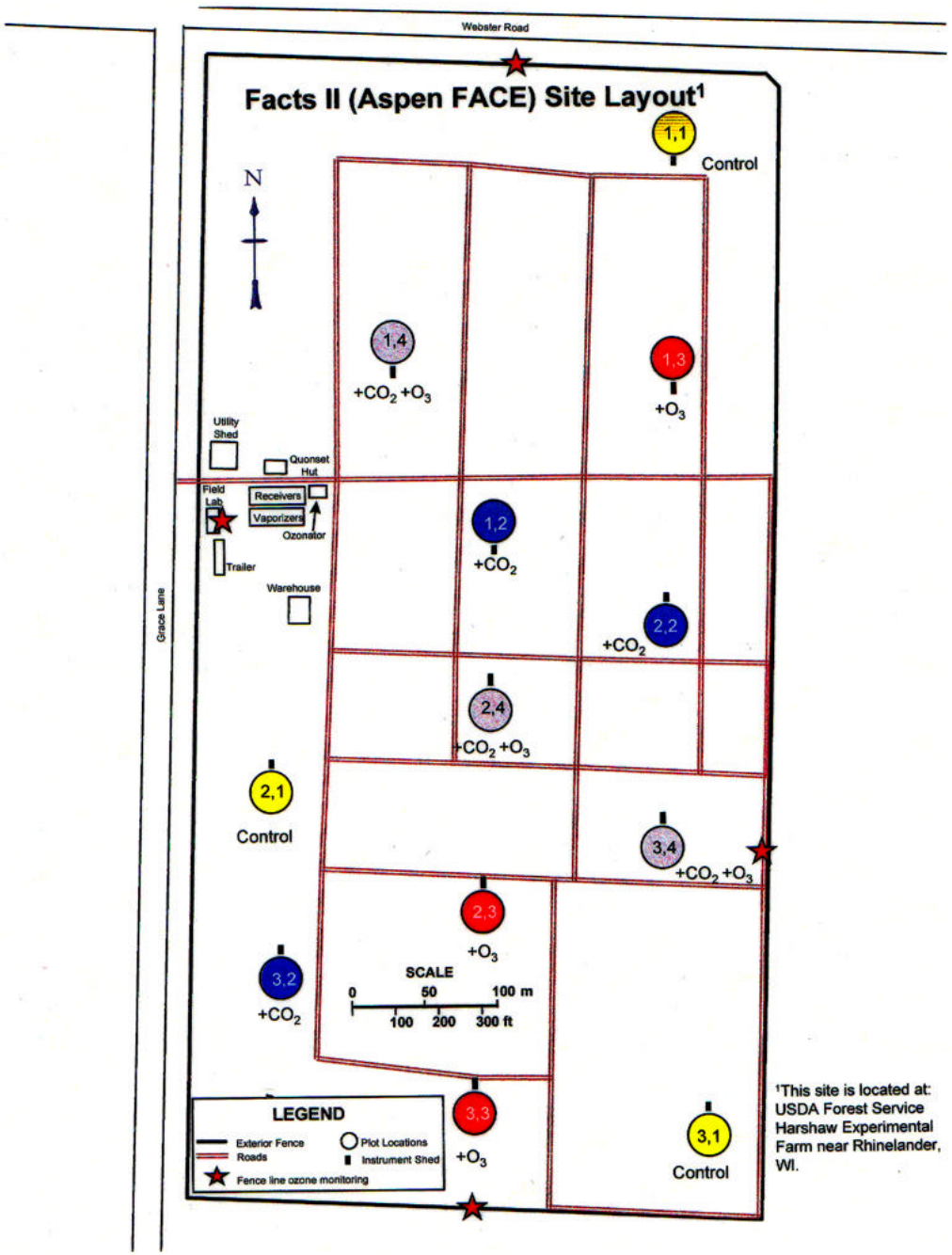
Kevin E. Percy, CFS

The Species : *Populus tremuloides, Betula papyrifera, Acer saccharum*

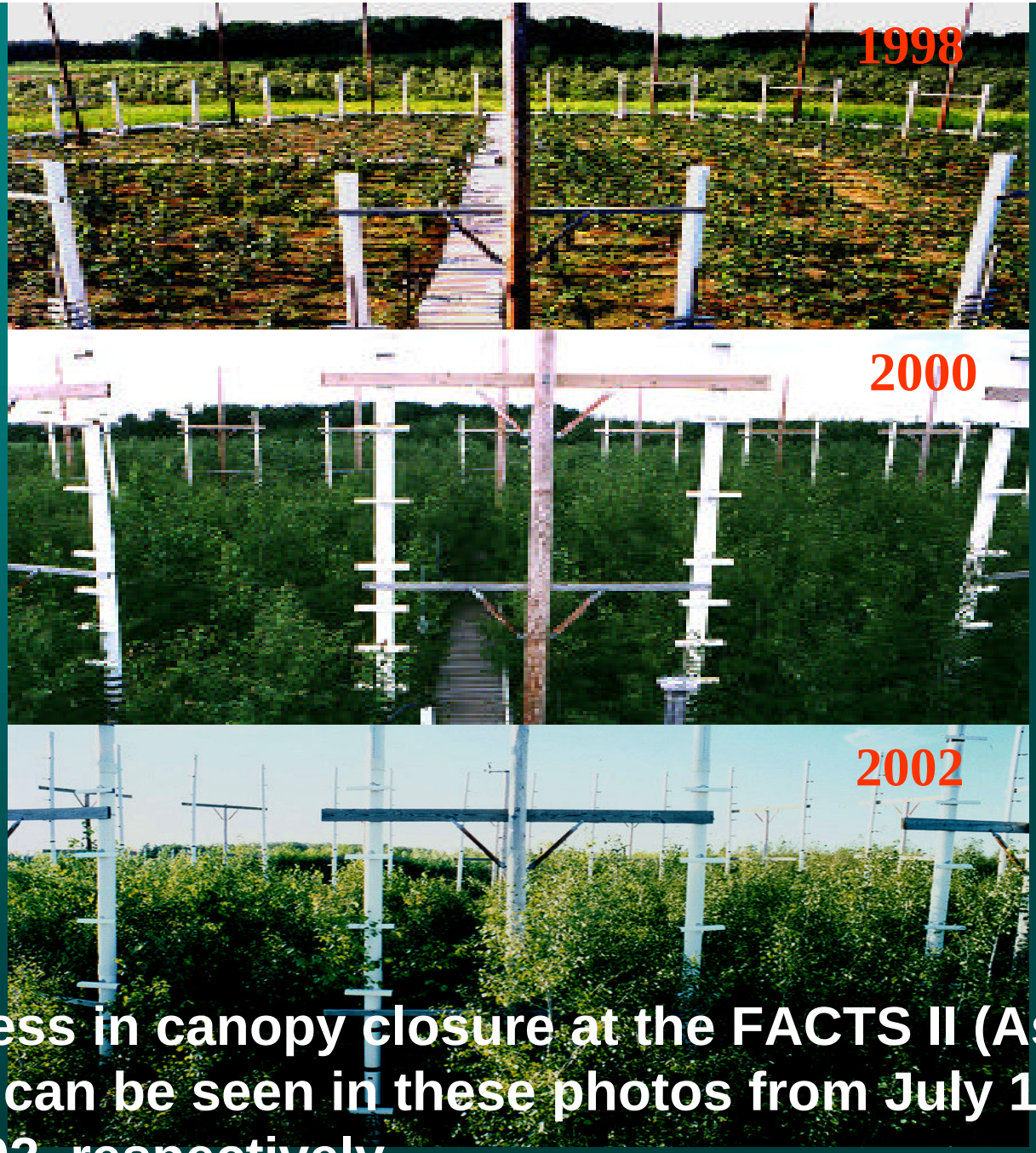
50 scientists – 8 countries

Primary Sponsors: DOE, USFS, MTU, CFS, NSF, USDA-NRI


Aspen/Birch
Aspen/Maple
Aspen

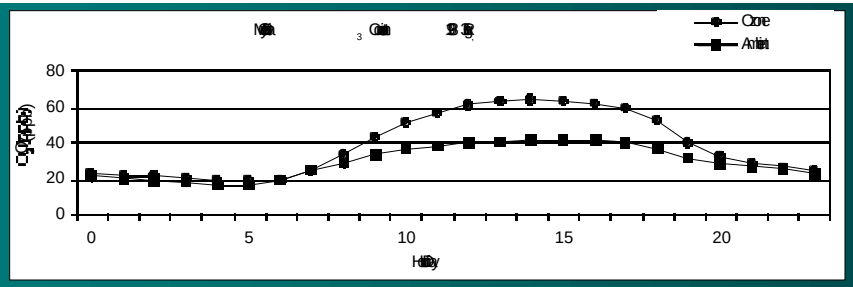


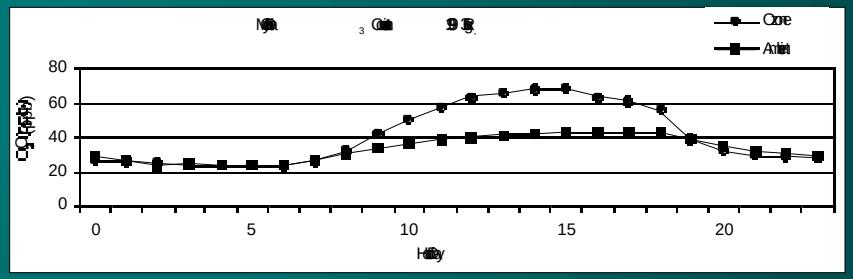
[1]This site is located at: USDA Forest Service Harshaw Experimental Farm near Rhinelander, WI.

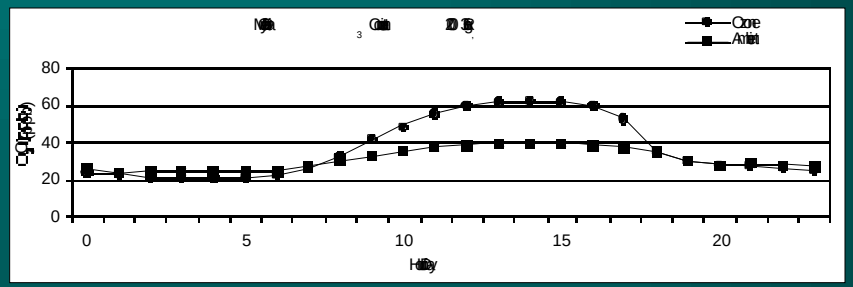


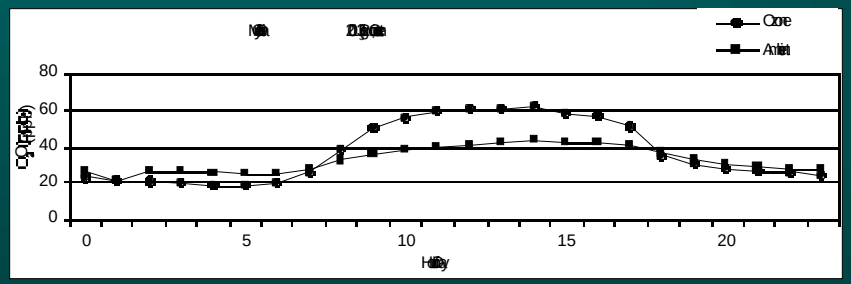
- Progress in canopy closure at the FACTS II (Aspen FACE) project can be seen in these photos from July 1998, 2000, and 2002, respectively.

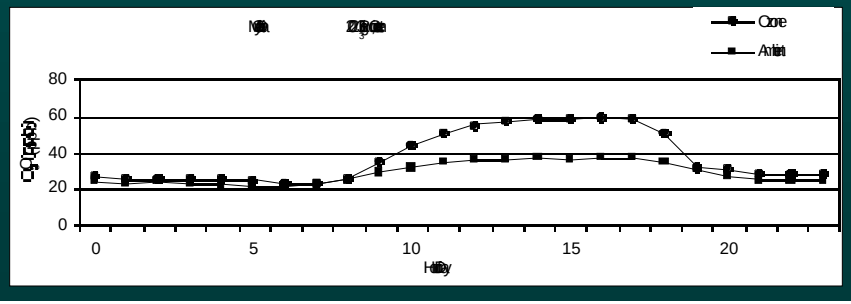

PRAXAIR
TRAILIGAZ
460 VOLTS
WARNING

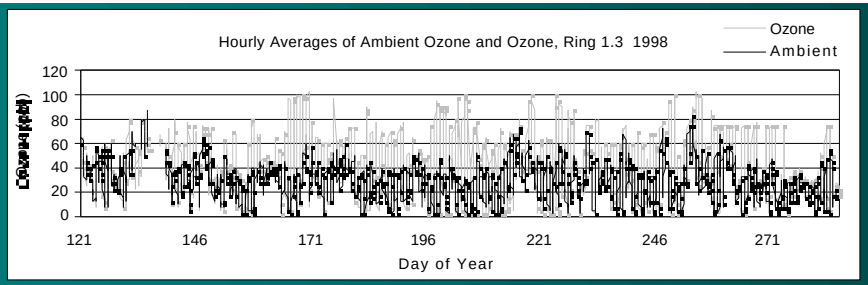

Ozone
Ambient
80
60
40
20
0
0
5
10
15
20

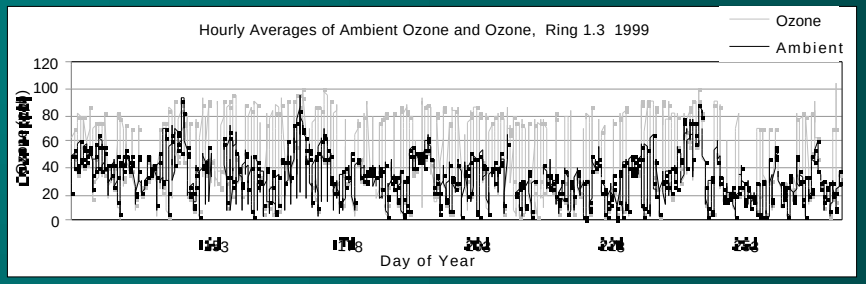

Ozone
Ambient
80
60
40
20
0
0
5
10
15
20

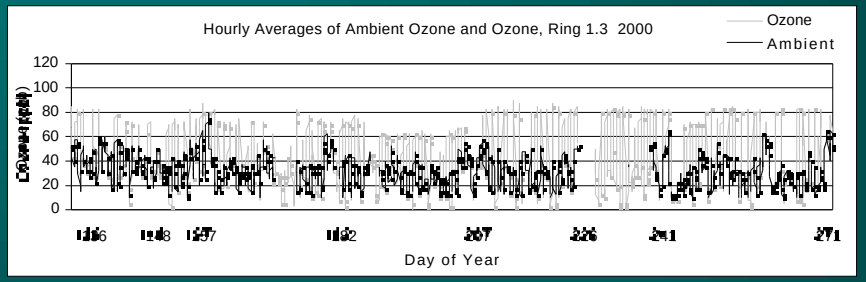

Ozone
Ambient
80
60
40
20
0
0
5
10
15
20

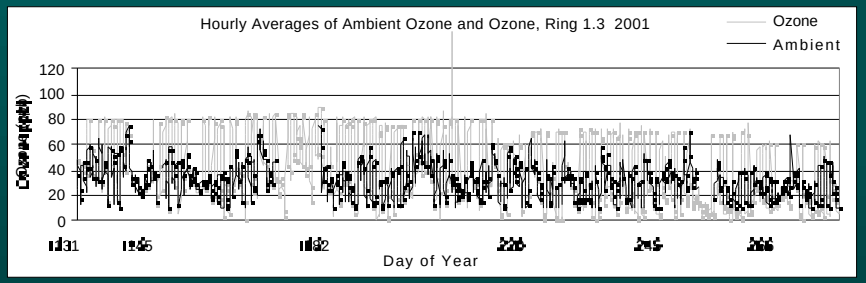

Ozone
Ambient
80
60
40
20
0
0
5
10
15
20

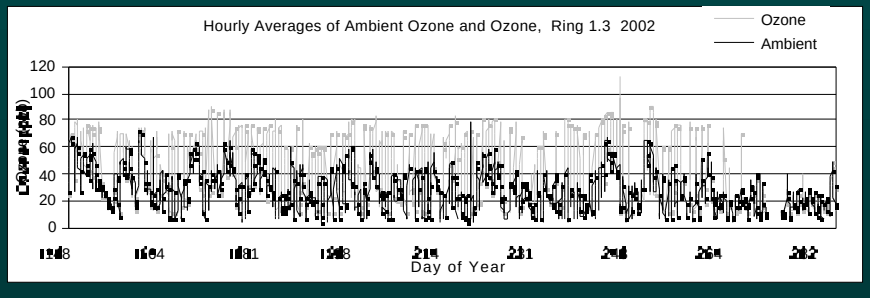

Ozone
Ambient
80
60
40
20
0
0
5
10
15
20


Hourly Averages of Ambient Ozone and Ozone, Ring 1.3 1998
Ozone
Ambient
120
100
80
60
40
20
0
121
146
171
196
221
246
271
Day of Year

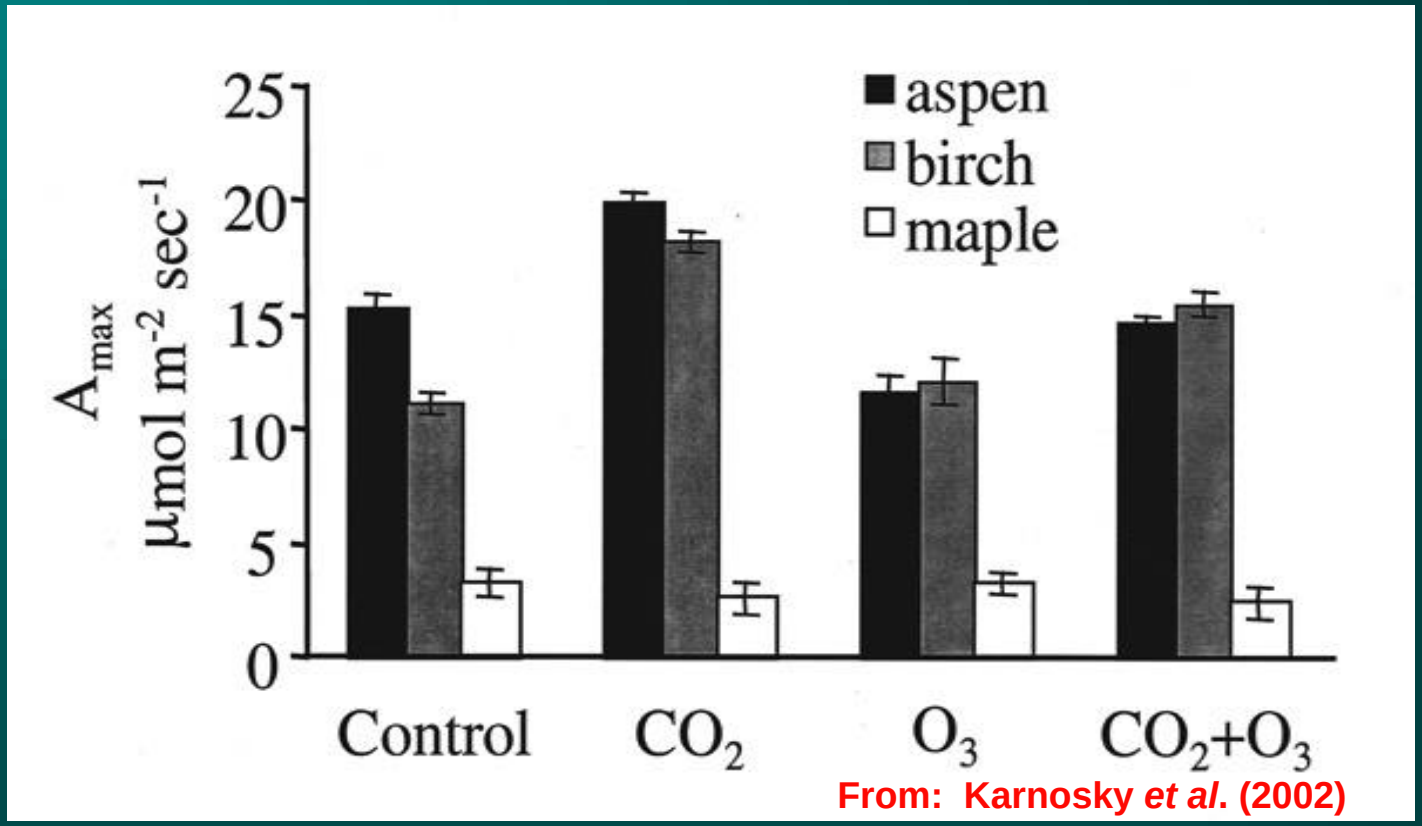

Hourly Averages of Ambient Ozone and Ozone, Ring 1.3 1999
Ozone
Ambient
120
100
80
60
40
20
0
Day of Year


Hourly Averages of Ambient Ozone and Ozone, Ring 1.3 2000
Ozone
Ambient
120
100
80
60
40
20
0
Day of Year


Hourly Averages of Ambient Ozone and Ozone, Ring 1.3 2001
Ozone
Ambient
120
100
80
60
40
20
0
Day of Year


Hourly Averages of Ambient Ozone and Ozone, Ring 1.3 2002
Ozone
Ambient
120
100
80
60
40
20
0
Day of Year

Moderation of CO_2 Responses: Ozone Photosynthesis

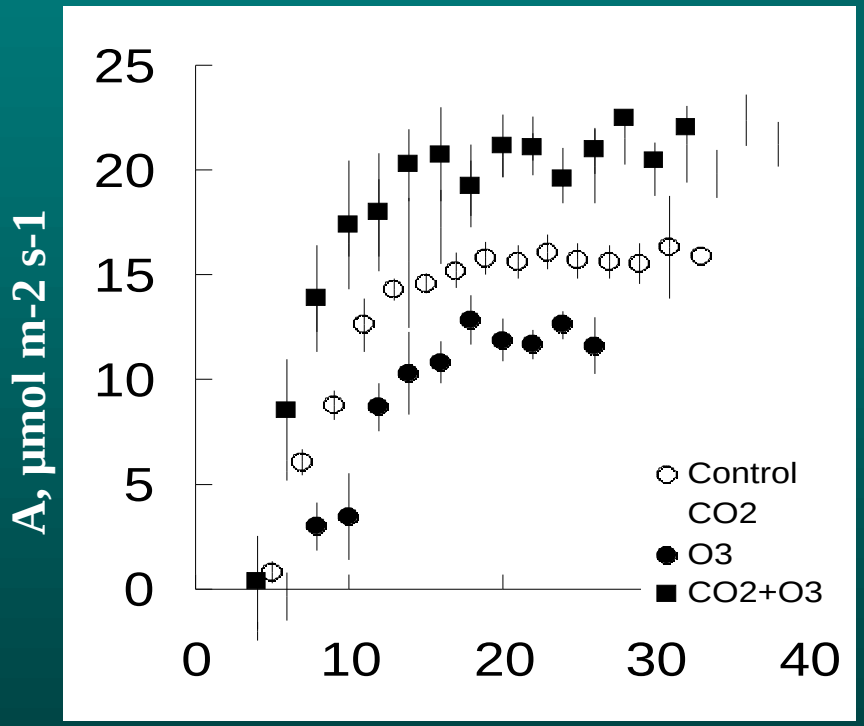


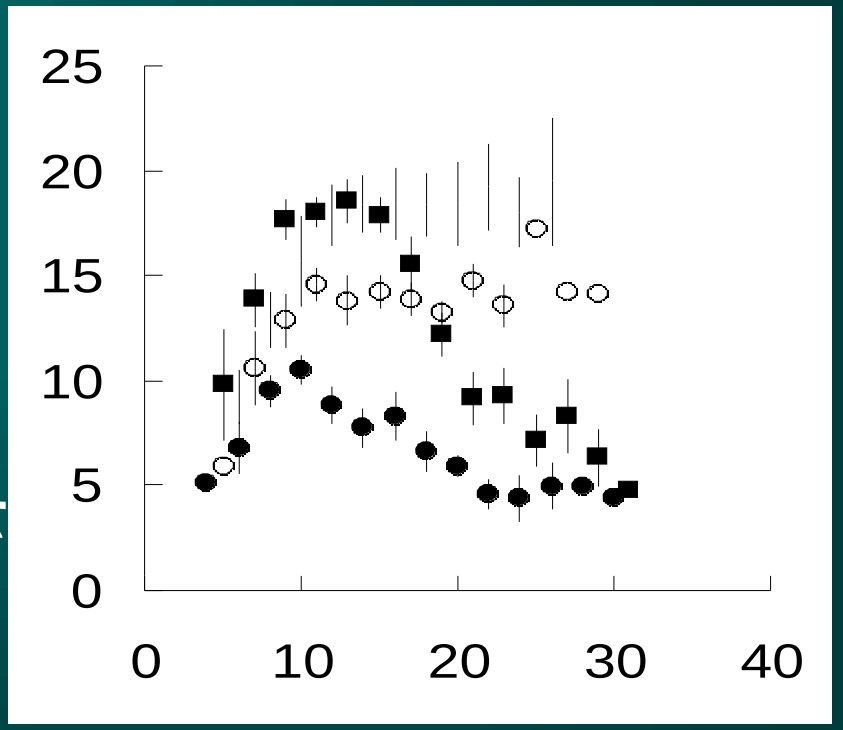
From: Karnosky *et al*. (2002)

- Mean values of instantaneous photosynthesis at the Aspen Face Site

  Data from: Noormets, Sharma, Kubiske, Davey, and Long

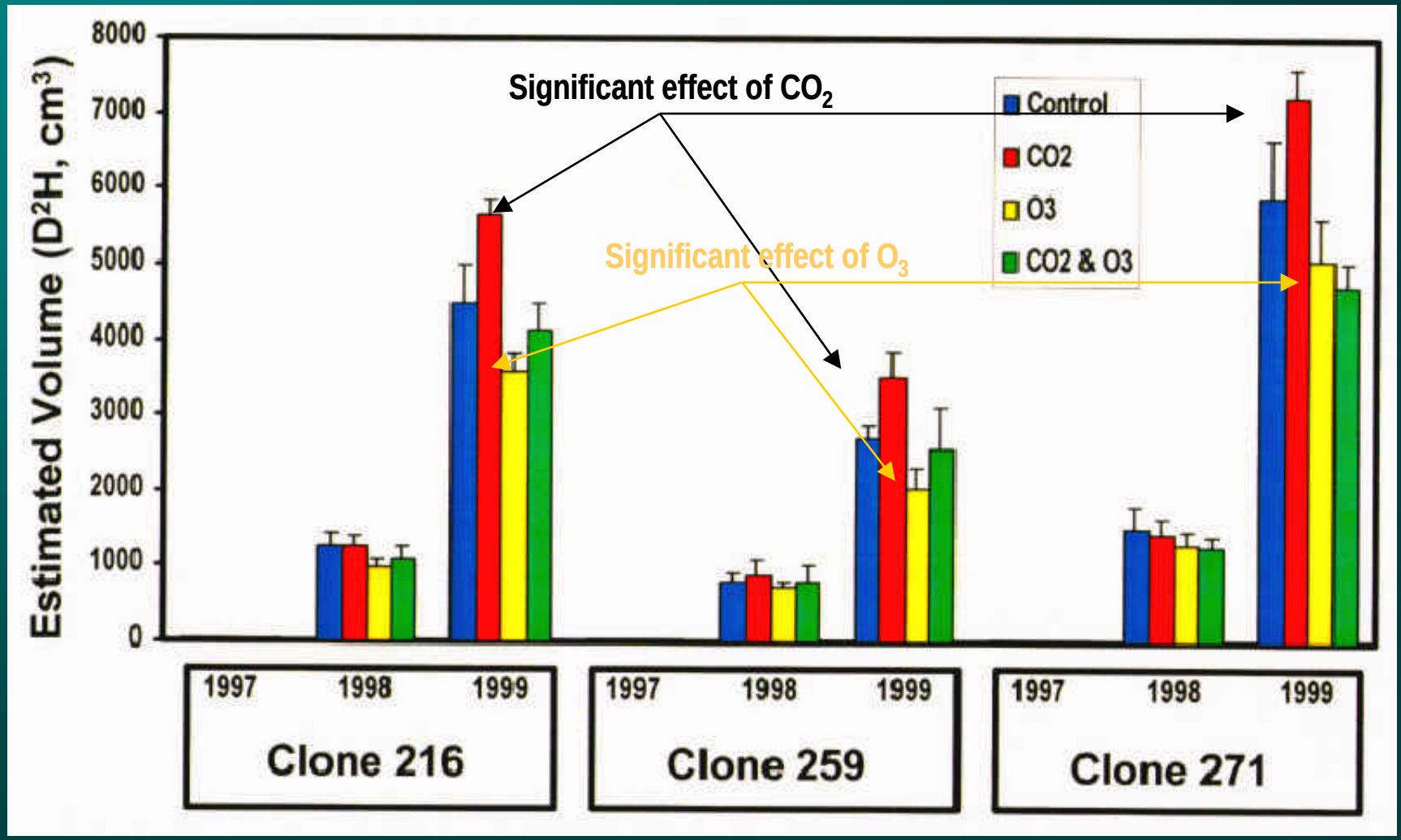
Moderation of CO_2 Responses by O_3: Gas Exchange





From: Noormets *et al*. 2001

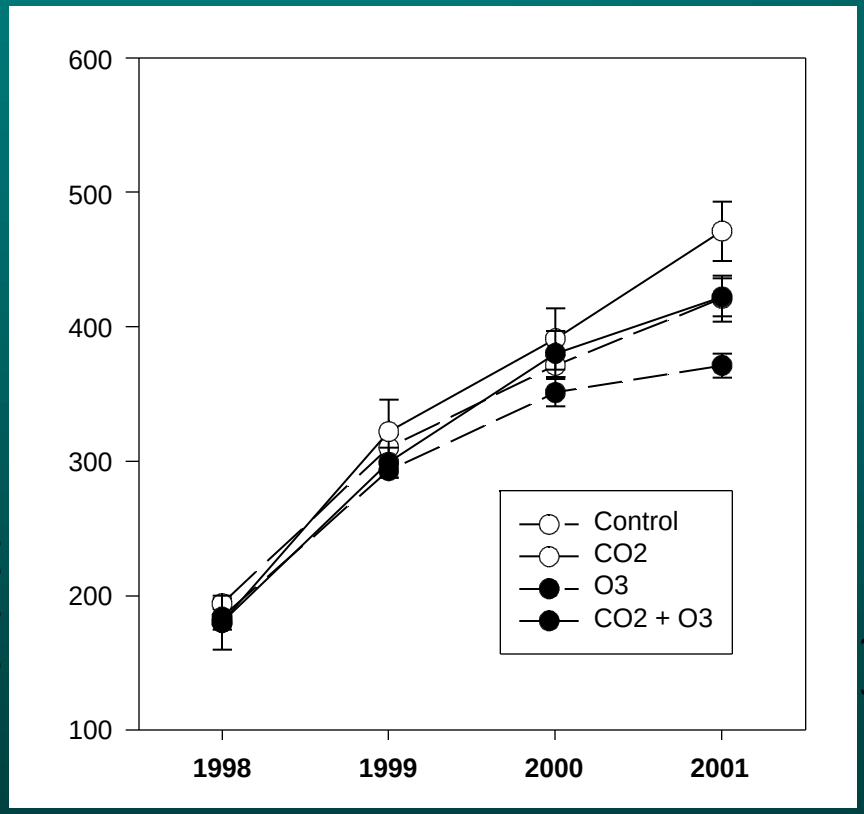
Results: Effects of CO_2 and O_3 on Aspen

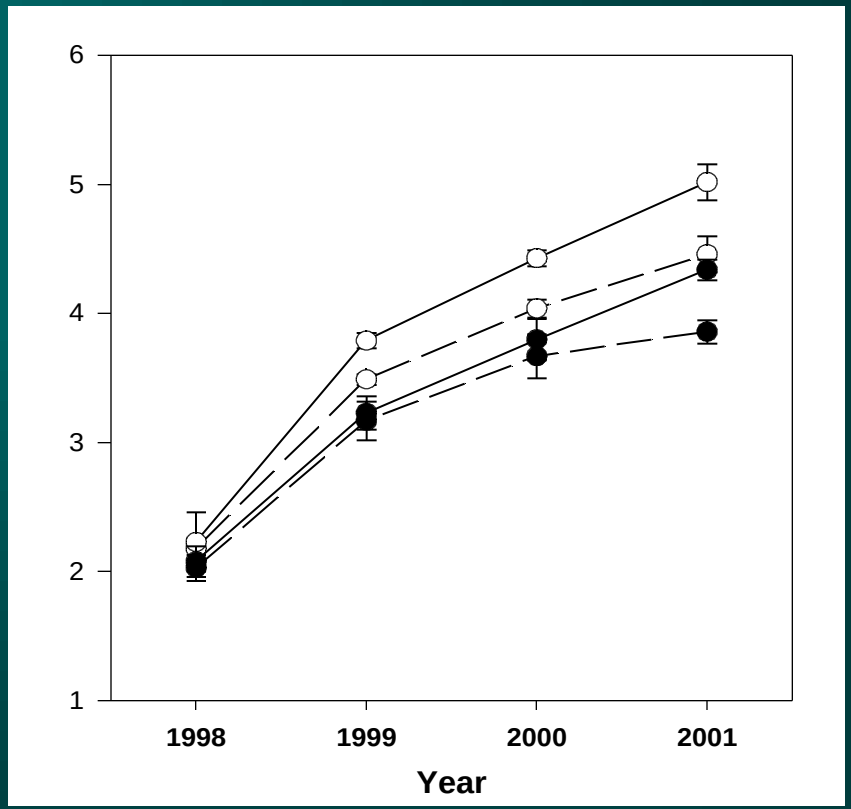


Brookhaven Science Associates

Brookhaven National Laboratory

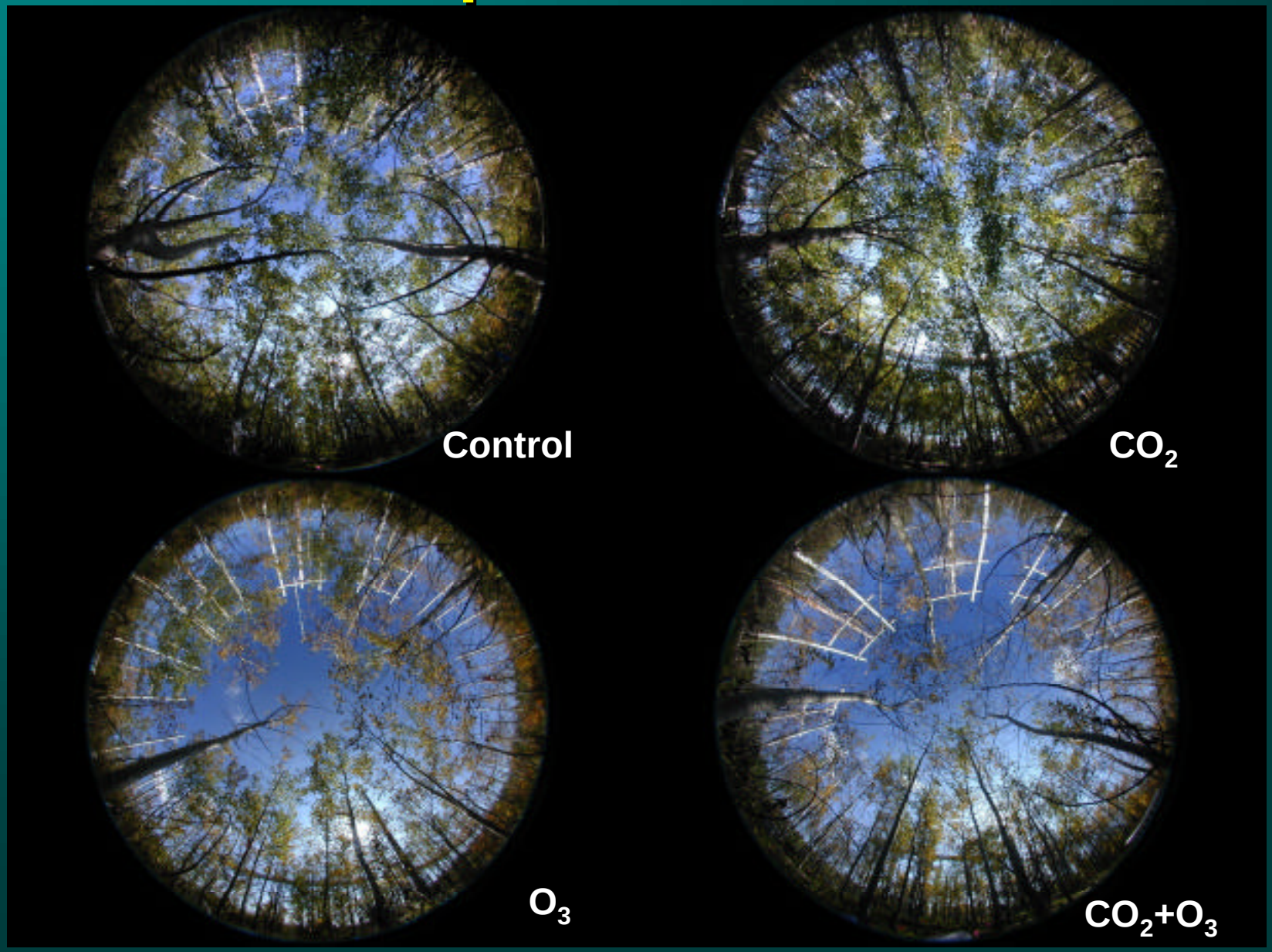
O_3 Moderates Aspen Growth Response to CO_2



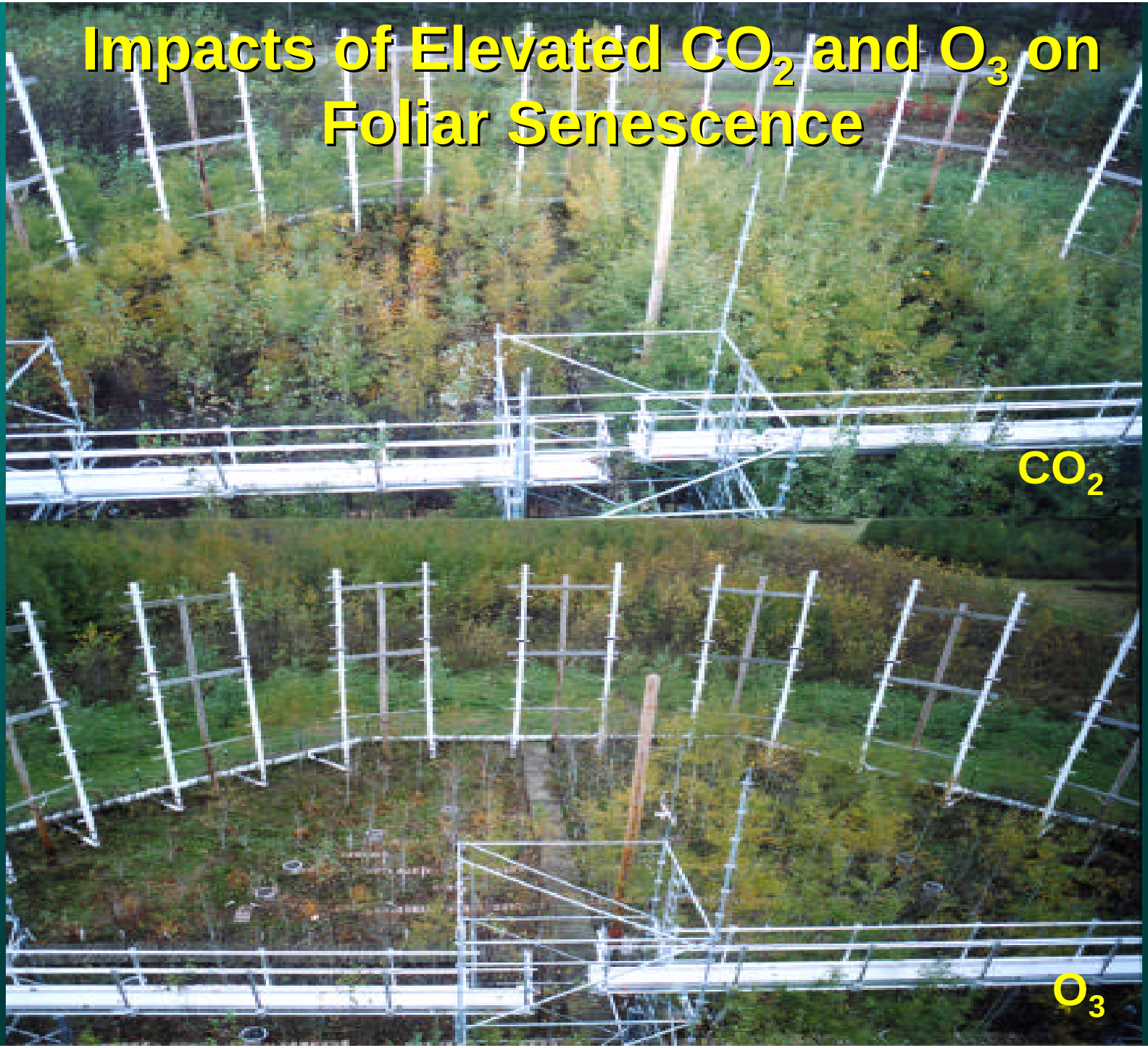


Percy *et al*. 2002, *Nature* 420:403-407

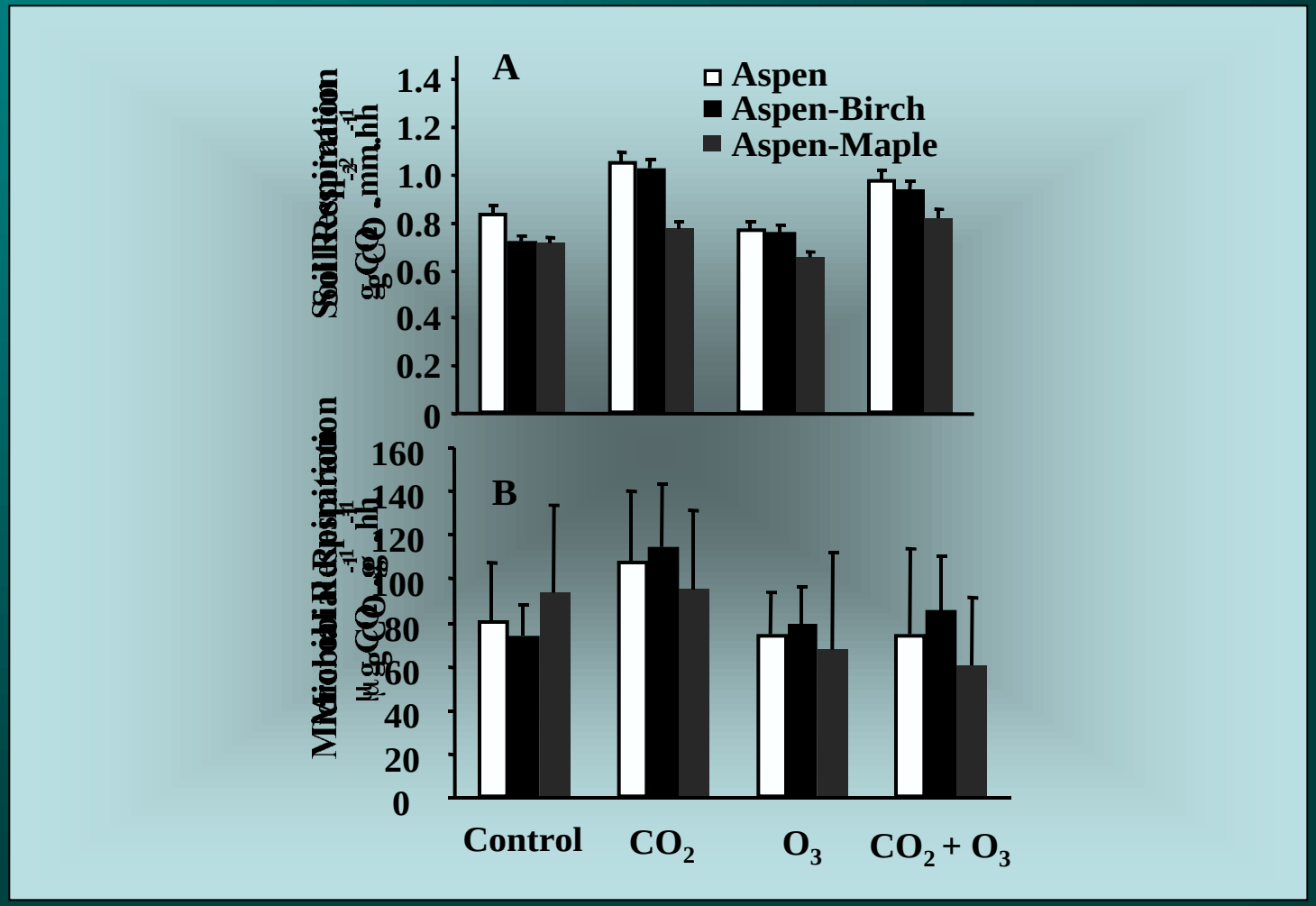
Aspen/Birch 2002



Impacts of Elevated CO_2 and O_3 on Foliar Senescence



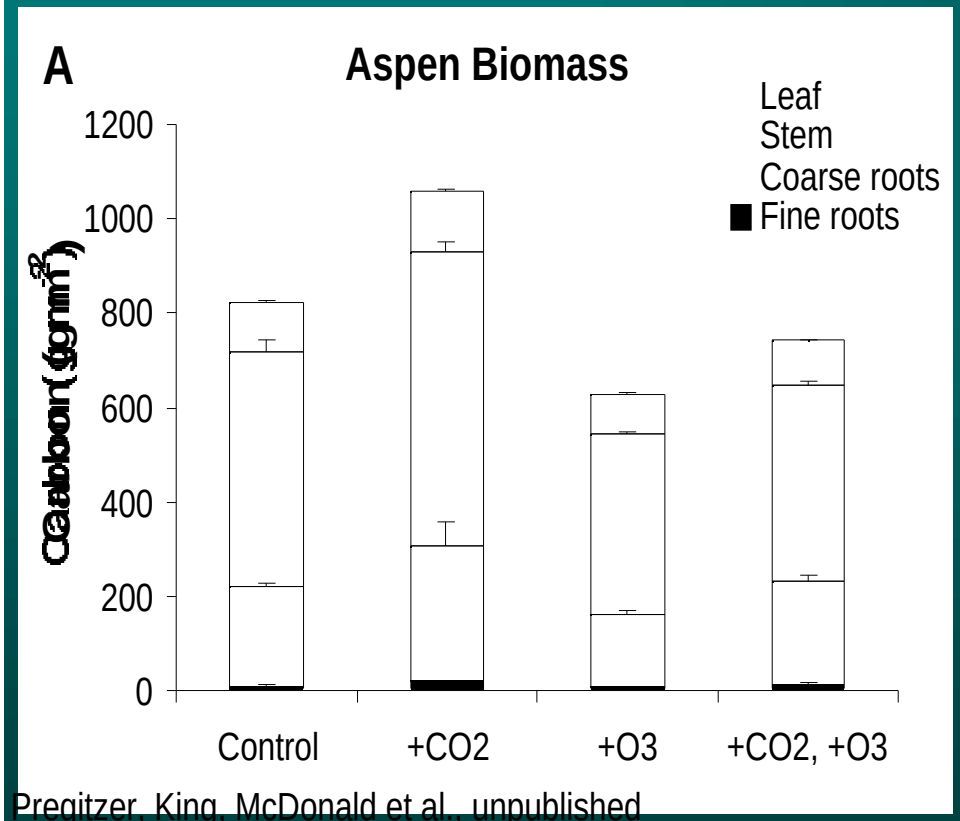
Moderation of CO_2 Responses: Ozone Belowground Respiration

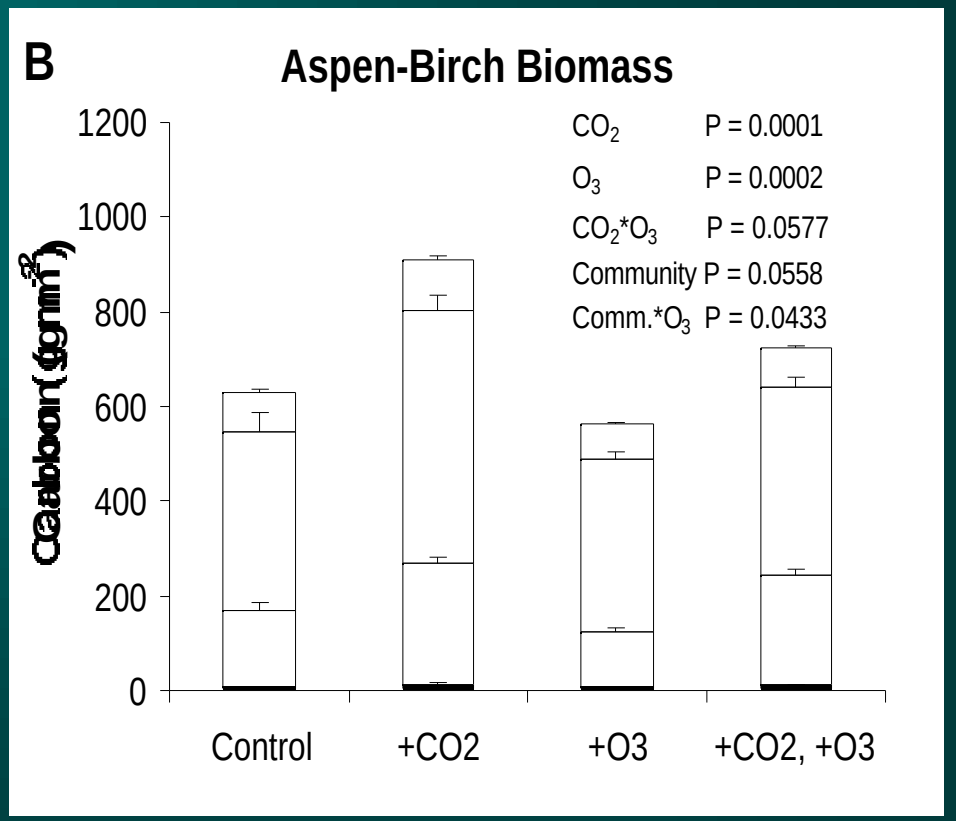


- Soil and microbial respiration values from the Aspen FACE project

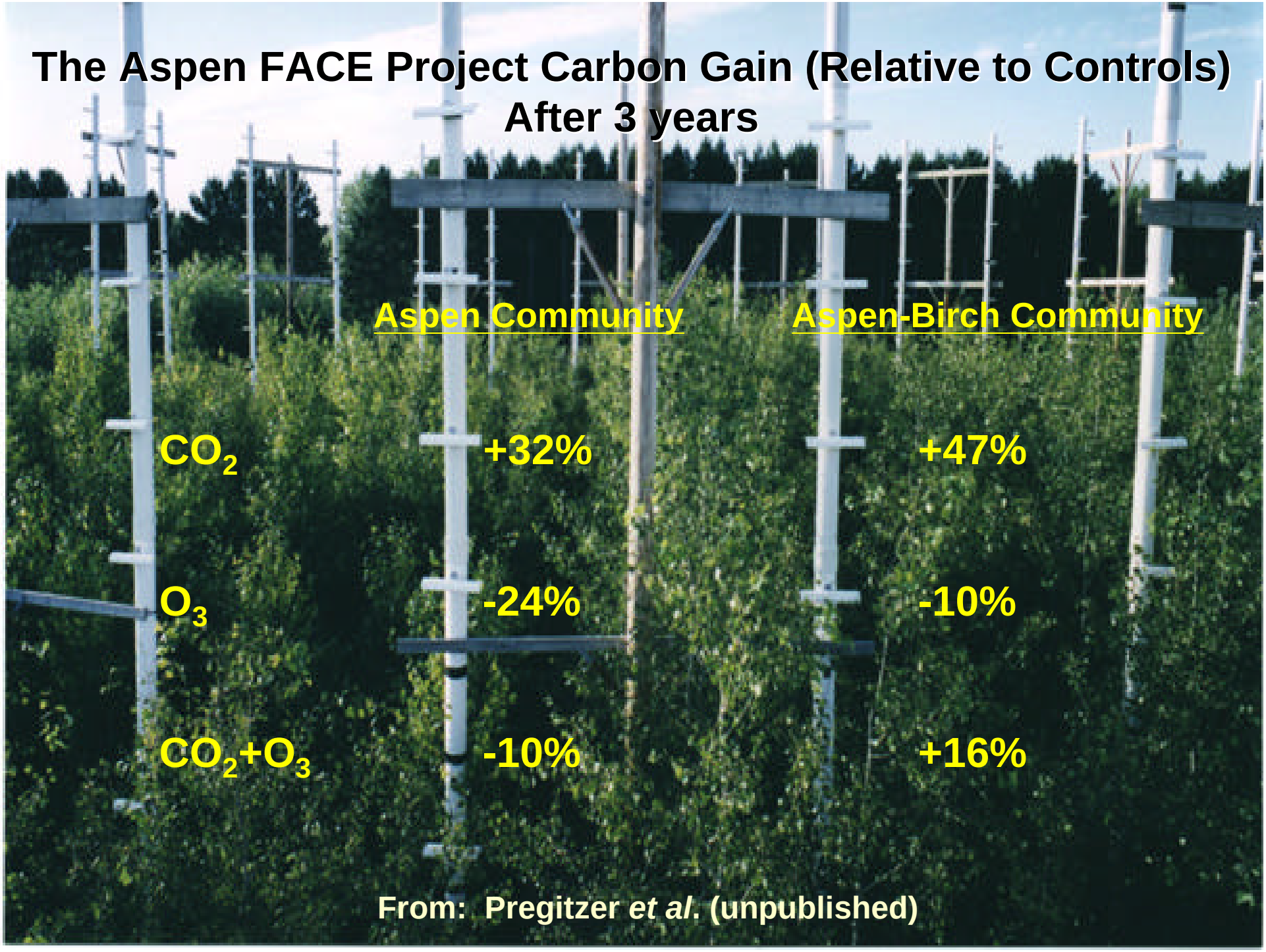
Data from: King *et al*. 2001, *Oecologia* 128:237-250; Phillips *et al*. 2002, *Oecologia* 131(2):236-244

Moderation of CO_2 Responses: Ozone Year 3 Biomass: Aspen FACE



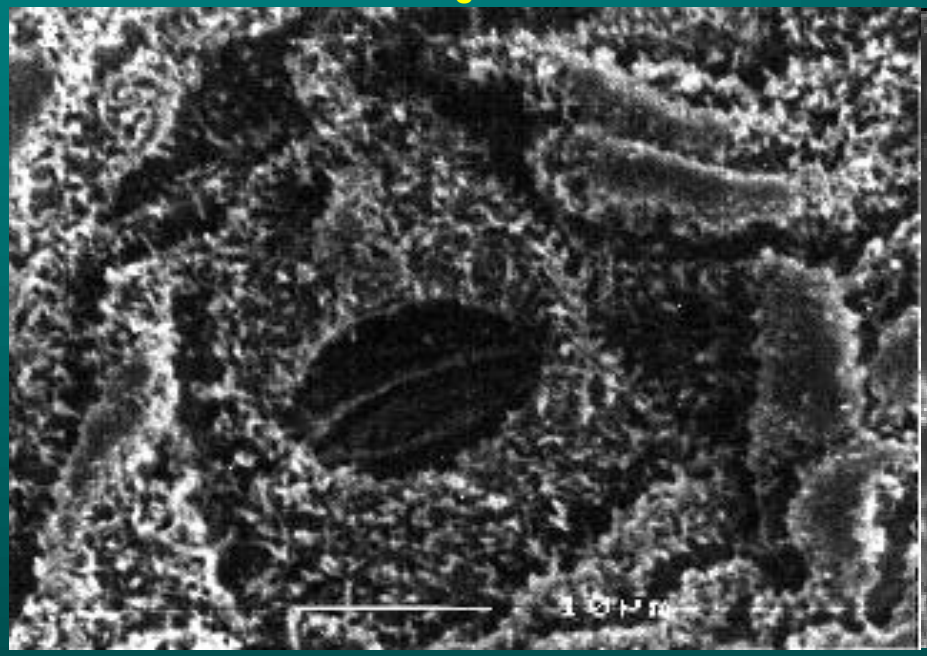


Pregitzer, King, McDonald et al., unpublished

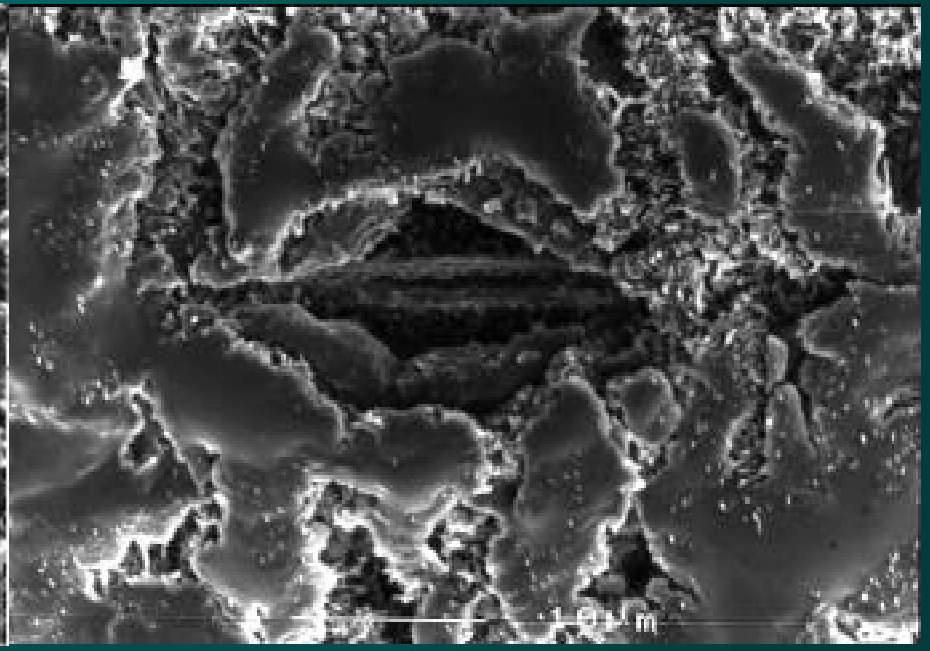

The Aspen FACE Project Carbon Gain (Relative to Controls)
After 3 years
Aspen Community
Aspen-Birch Community
CO_2
+32%
+47%
O_3
-24%
-10%
CO_2+O_3
-10%
+16%
From: Pregitzer *et al*. (unpublished)

O_3 Effects on Host/Pest Interactions

Clone 259 Low O_3 (Rhinelander, WI)

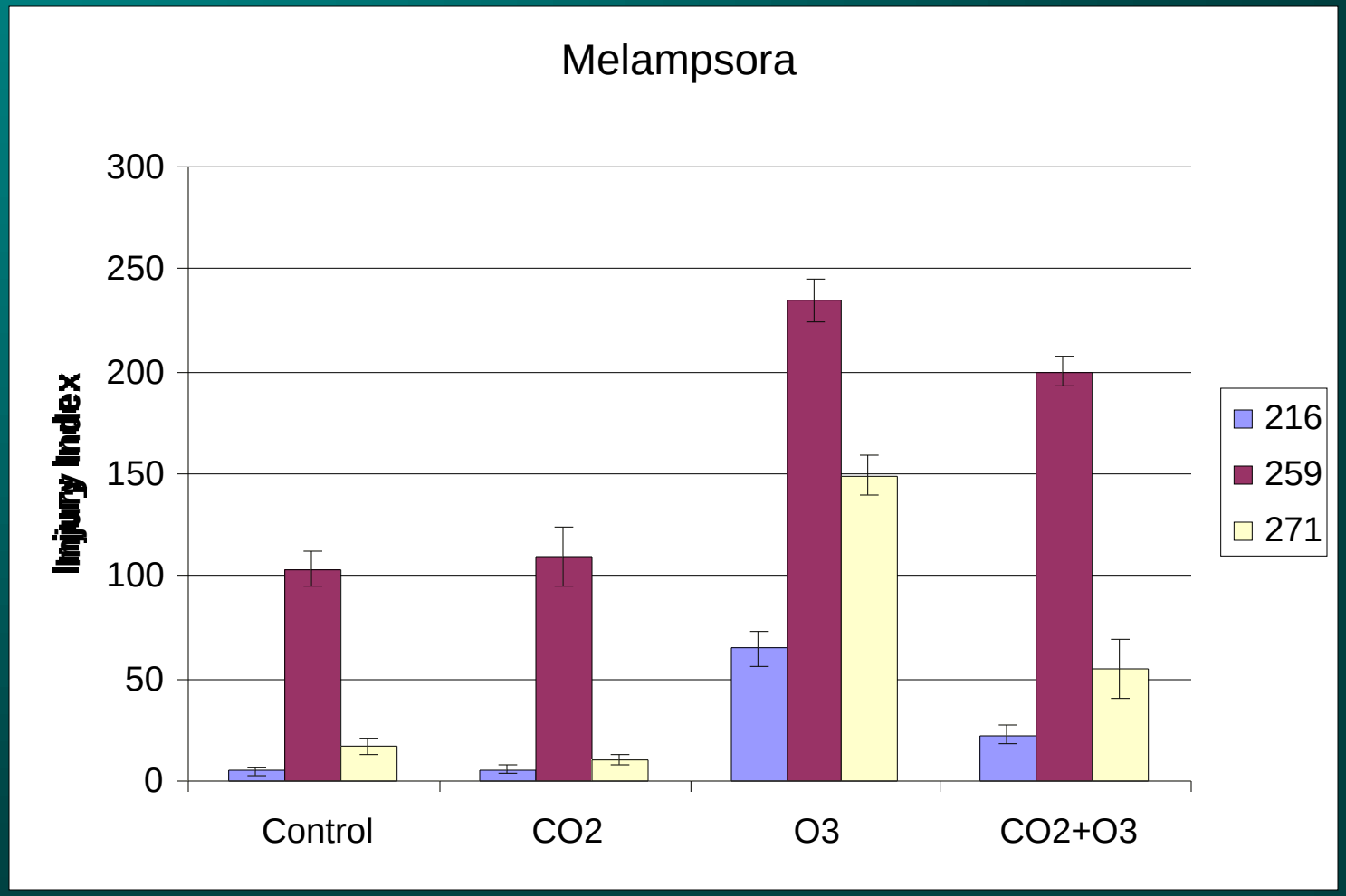


Clone 259 High O_3 (Kenosha, WI)



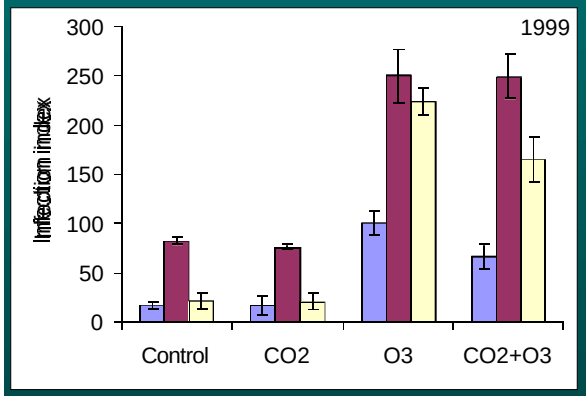
- Cuticle as first line of defense against pests
- Link of ambient O_3 to *P. tremuloides* leaf epicuticular wax changes
  - Mankovska, Percy & Karnosky 1998, *Ekológia* 18:200-210

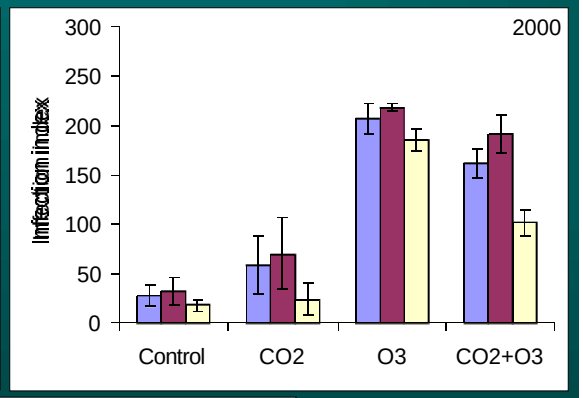
O_3 Effects on Host/Pest Interactions

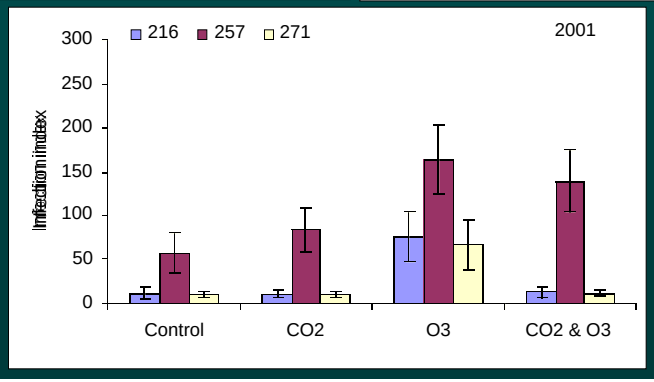


- Link of elevated O_3 to *Melampsora* leaf rust in *P. tremuloides*
  - Karnosky *et al*. 2002, *Global Change Biol*. 8:1-10

O_3 Predisposition of Aspen to *Melampsora* Rust

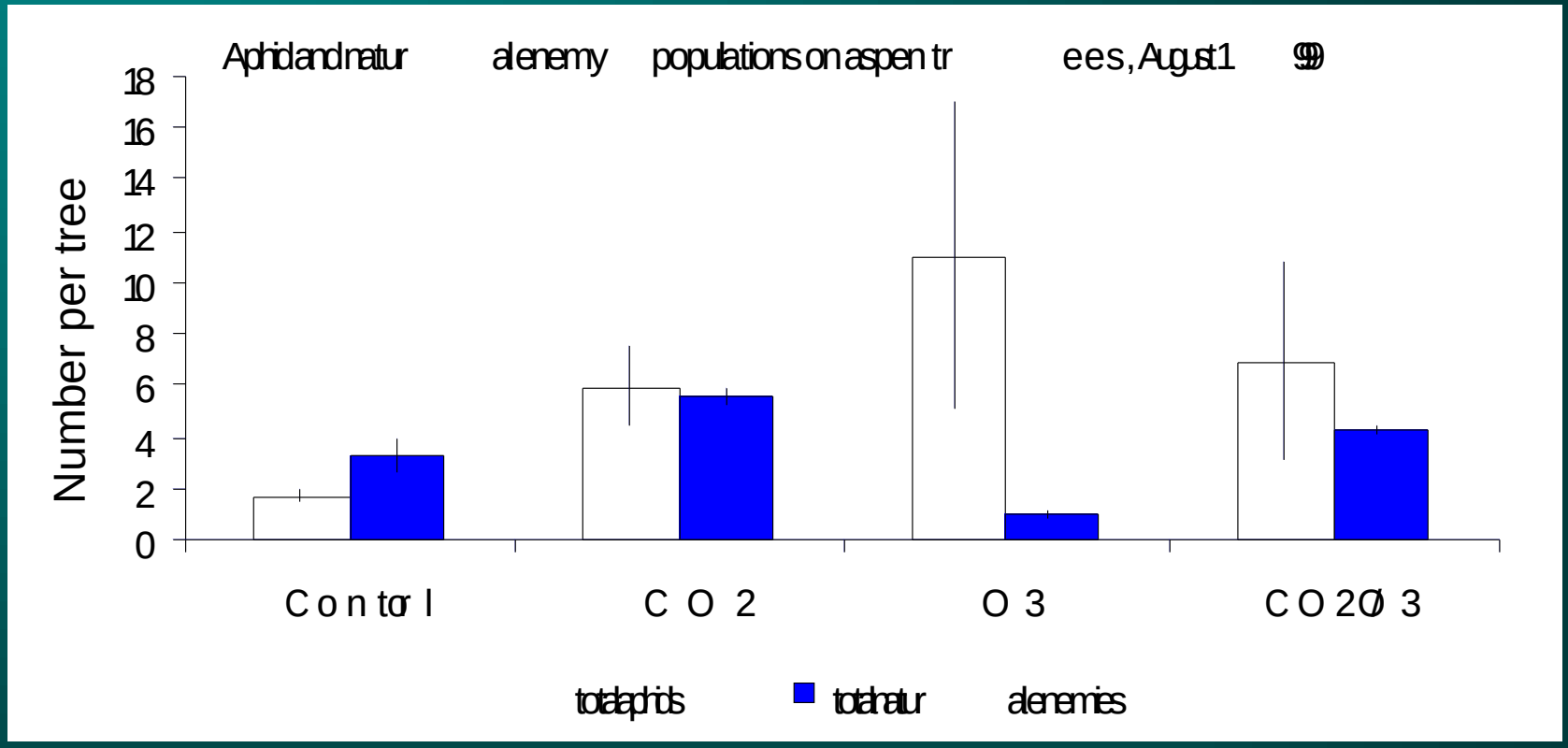






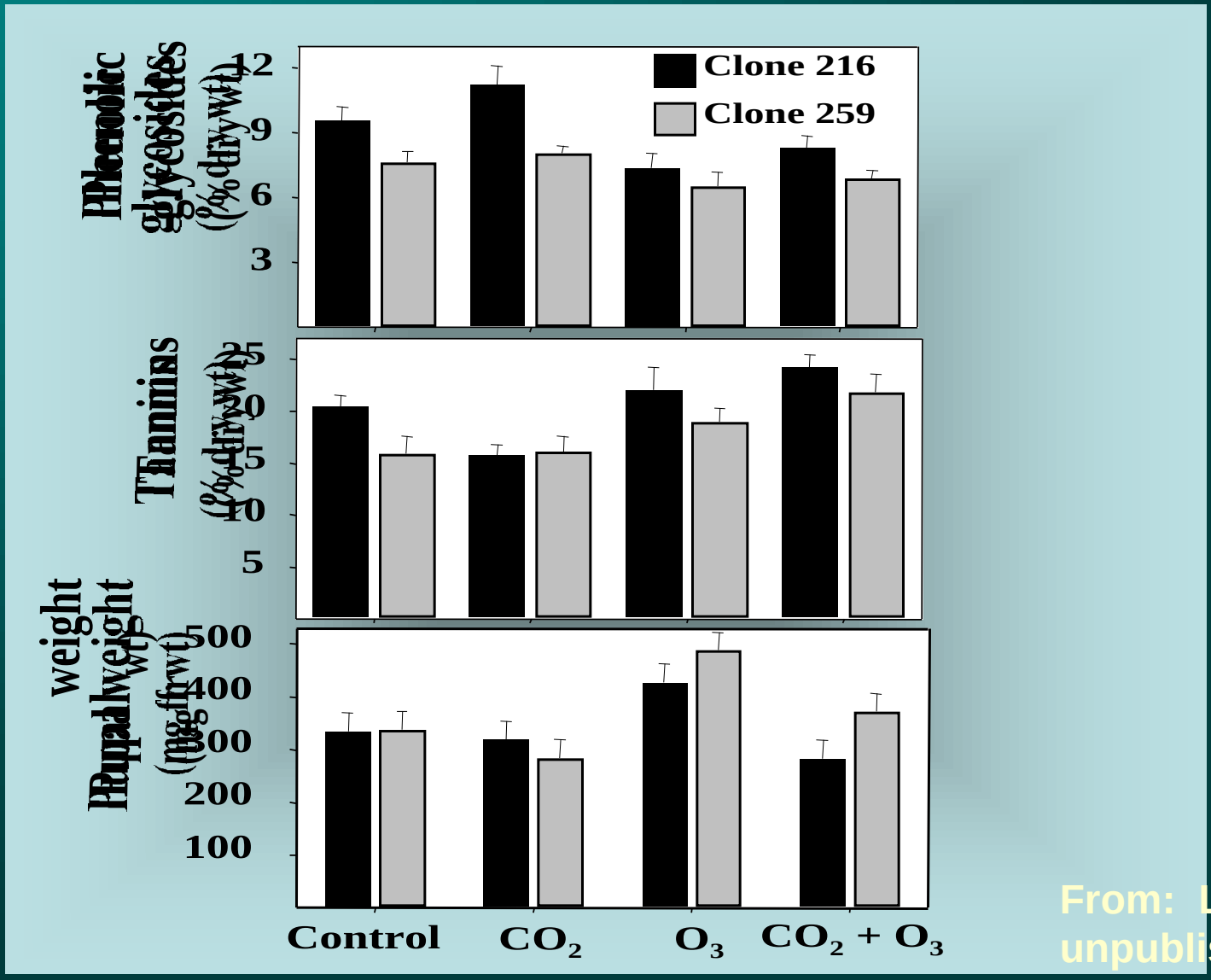
Interaction of Aspen/Aphids/O_3

O_3/Pest Interactions



- O_3 can also affect natural enemies of insects as documented by Percy *et al*. 2002, *Nature* 420:403-407.

Moderation of CO_2 Responses by O_3: Trophic Interactions

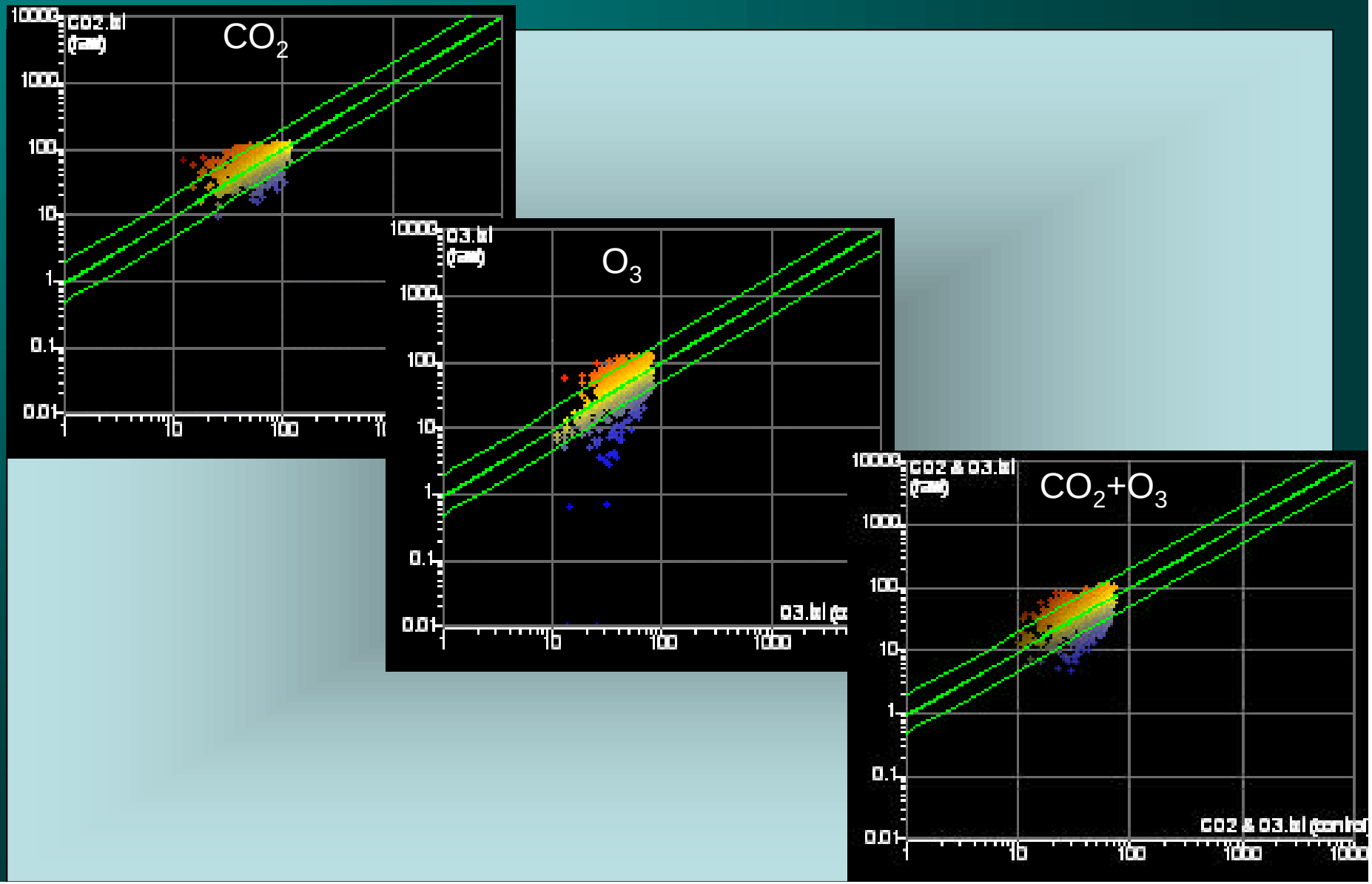


From: Lindroth, unpublished

Impacts of O_3 and/or CO_2 on Gene Expression

- Study of antioxidant gene expression (1997)
- Antioxidant gene isolation and reinsertion (1998)
- Slot Blot (16-20) – Sharma (2001)
- Membrane Arrays (1000's of poplar EST's) (2002)
- The near future with genes controlling
  - (a) defense
  - (b) signal transduction
  - (c) growth
  - (d) metabolism
  - (e) structure

Expression of Genes Under Interacting CO_2 and O_3



Preliminary Findings
Aspen FACE Project

- **Are forests net carbon sources or sinks?**
  - **Transition from source to sink (3 yrs)**
  - **O_3 decreases sink strength (with or without elevated CO_2)**

- **Is carbon sequestered by trees stored for a long time in the soil?**
  - **Greater amounts of C are forming soil organic matter under elevated CO_2**
  - **More C may be stored as CO_2 concentration increases**
  - **More C is also exiting soils (respiration) so may not be net soil gain under elevated CO_2**

Preliminary Findings
Aspen FACE Project

- **Will more or less CO_2 be sequestered by forests as CO_2 levels rise?**
  - **Physiological/genetic responses cascading through to ecosystem level**
  - **CO_2 and O_3 have increased C and N flow through the system**
  - **Yes, more carbon is being stored in young aggrading forest over the short term (5 years) but O_3 offsets gains under CO_2**

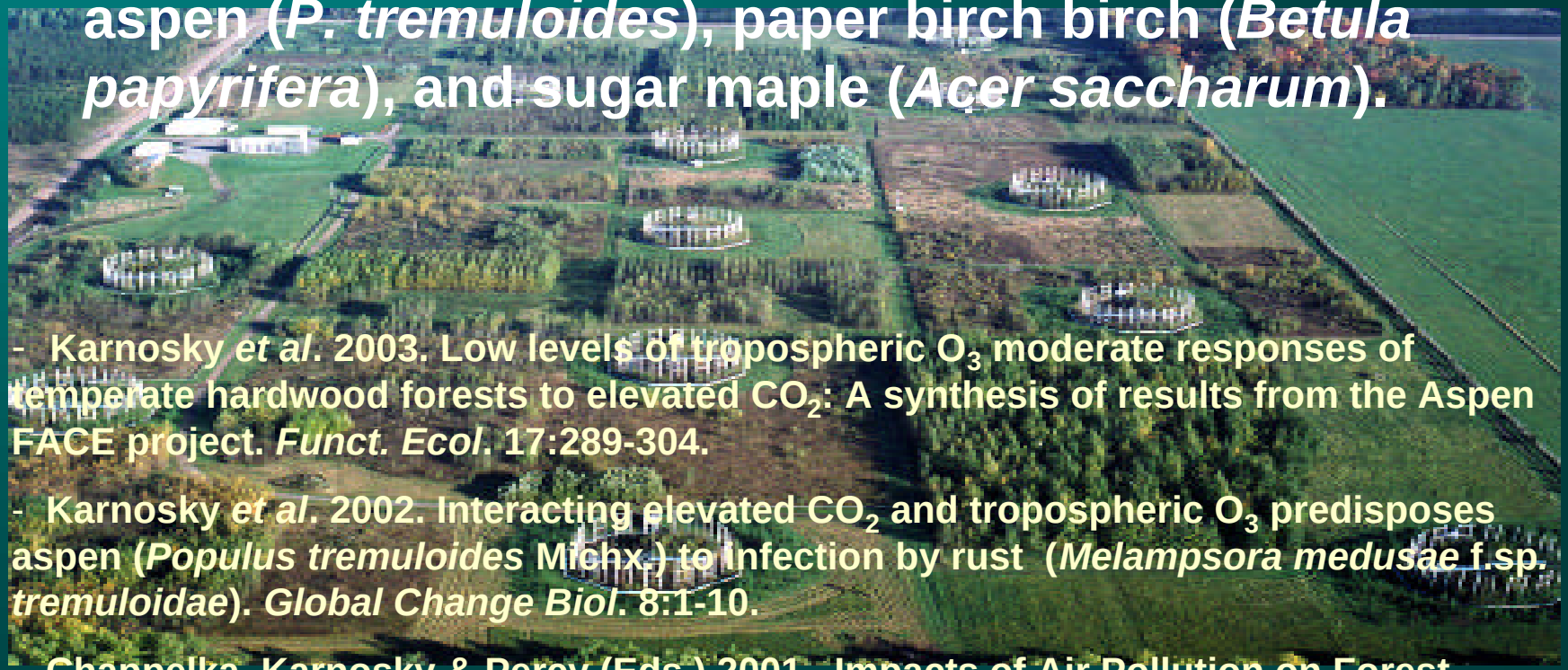
- **Will forests become more or less productive over time under increasing CO_2?**
  - **Other FACE's (Loblolly pine; Sweetgum) have detected diminishing growth enhancement with time**
  - **We have not seen it yet**

Preliminary Findings
Aspen FACE Project

- Will CO_2 "fertilization" be limited by rising O_3 levels, nitrogen limitation or drought?
  - Yes, offset by O_3
  - No indication of N limitation after five years
  - Evidence for water balance changes due to CO_2 and O_3
- How will increasing CO_2 affect insect and disease interactions?
  - Effects of CO_2 cascade through the system
  - Changes mediated by bottom-up (plant) and top-down (natural enemies) factors
  - Potential to alter insect community composition

O_3/CO_2 Interactions: *Conclusions*

- O_3 moderates the enhancements in growth, physiology, and ecological processes in trembling aspen (*P. tremuloides*), paper birch birch (*Betula papyrifera*), and sugar maple (*Acer saccharum*).



- Karnosky *et al*. 2003. Low levels of tropospheric O_3 moderate responses of temperate hardwood forests to elevated CO_2: A synthesis of results from the Aspen FACE project. *Funct. Ecol*. 17:289-304.

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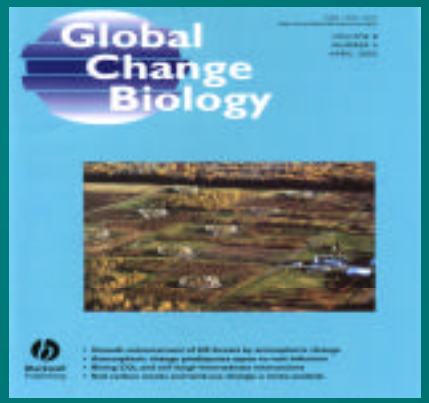
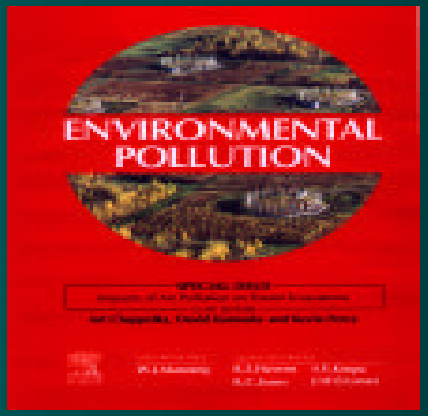
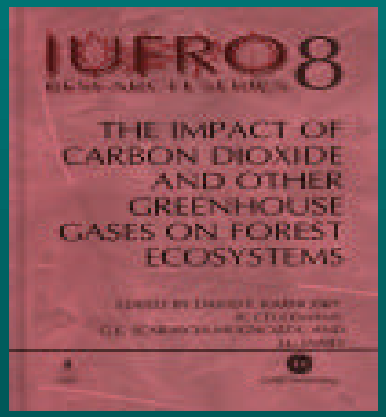
- Percy *et al*. 2002. Altered performance of forest pests under CO_2- and O_3-enriched atmospheres. *Nature* 420:403-307.





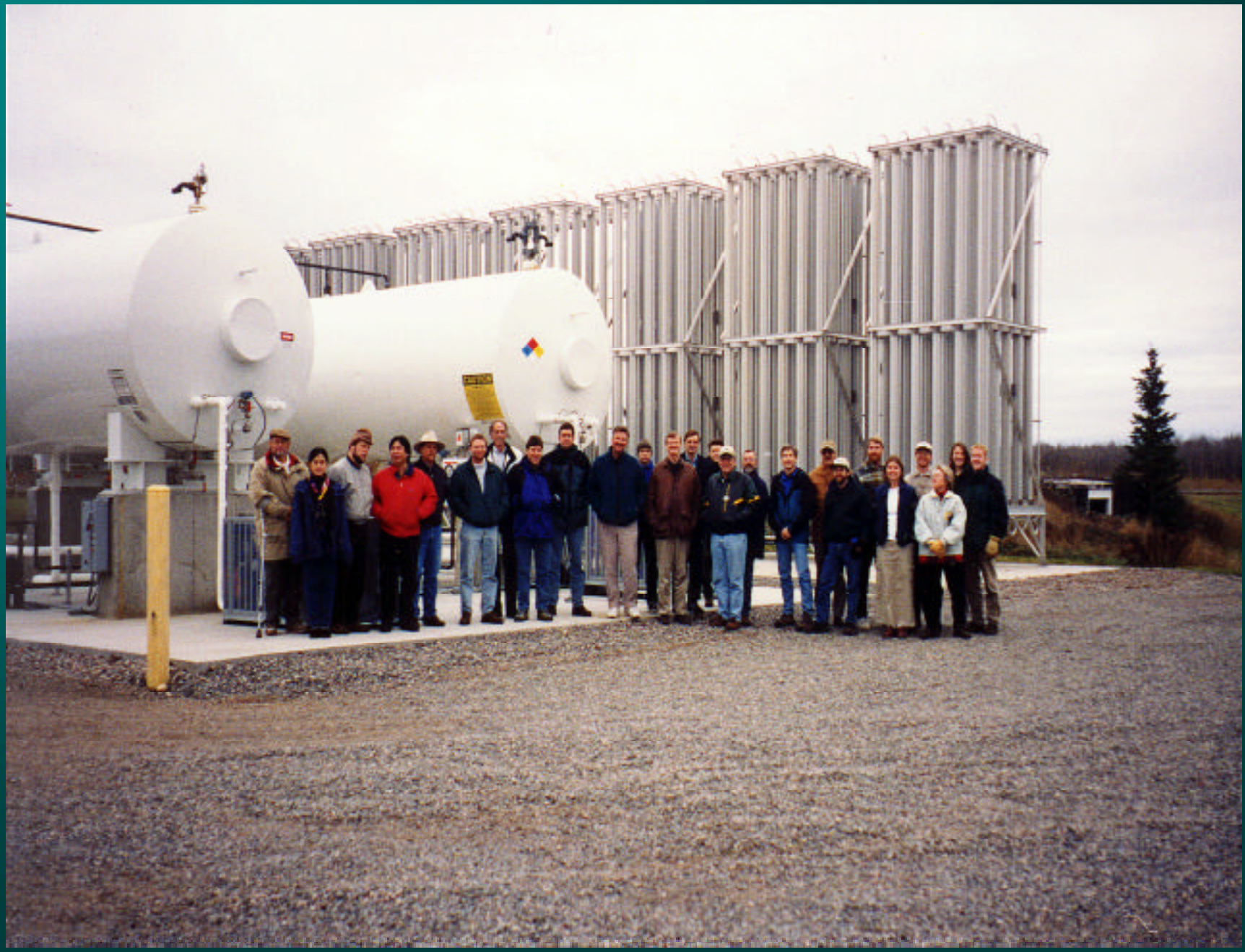


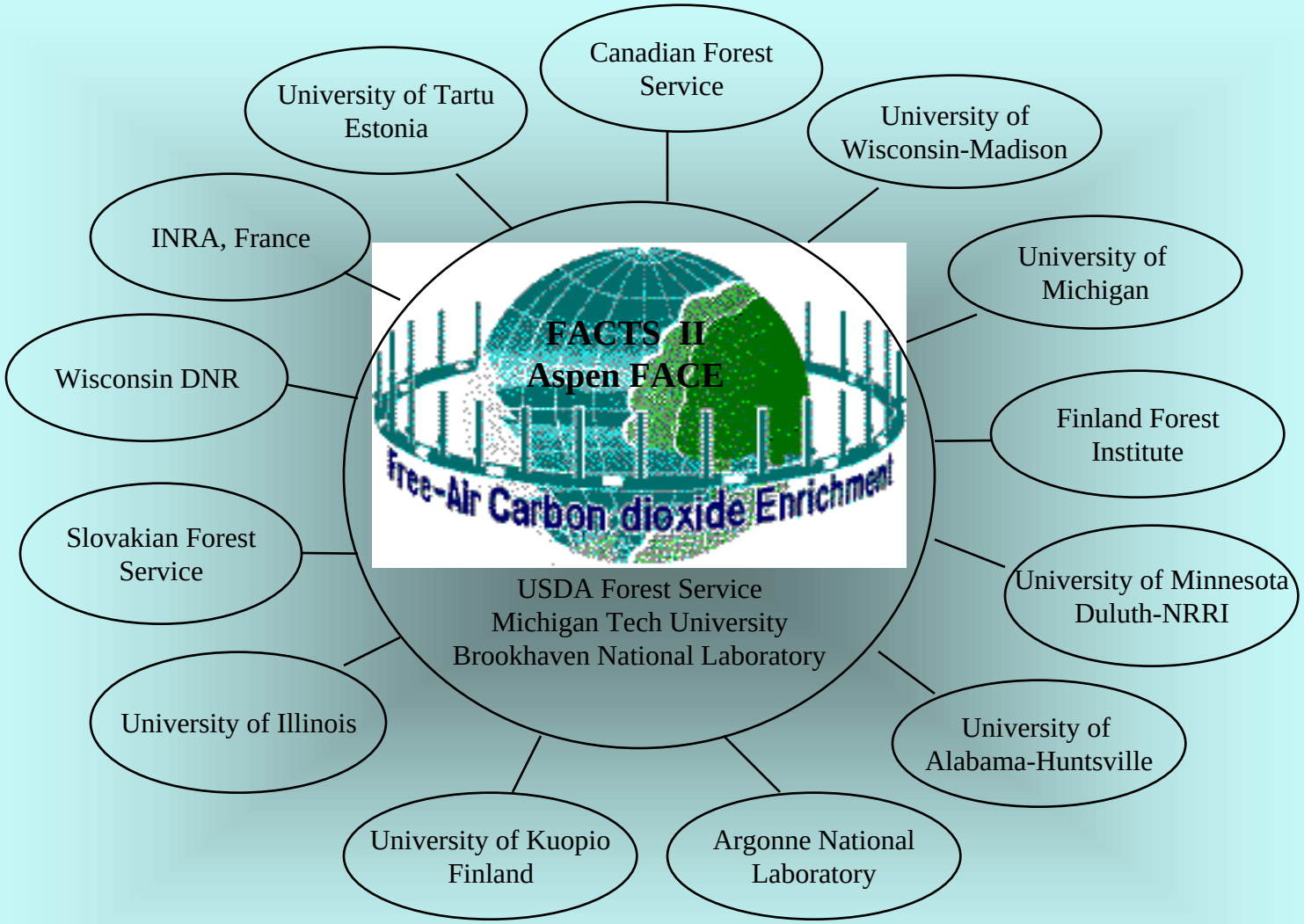
Getting the word out!

Air Pollution, Global Change and Forests in the New Millennium

(Editors: Karnosky, Percy, Chappelka, Simpson, Pikkarainen)

"In Press"





Research Partners

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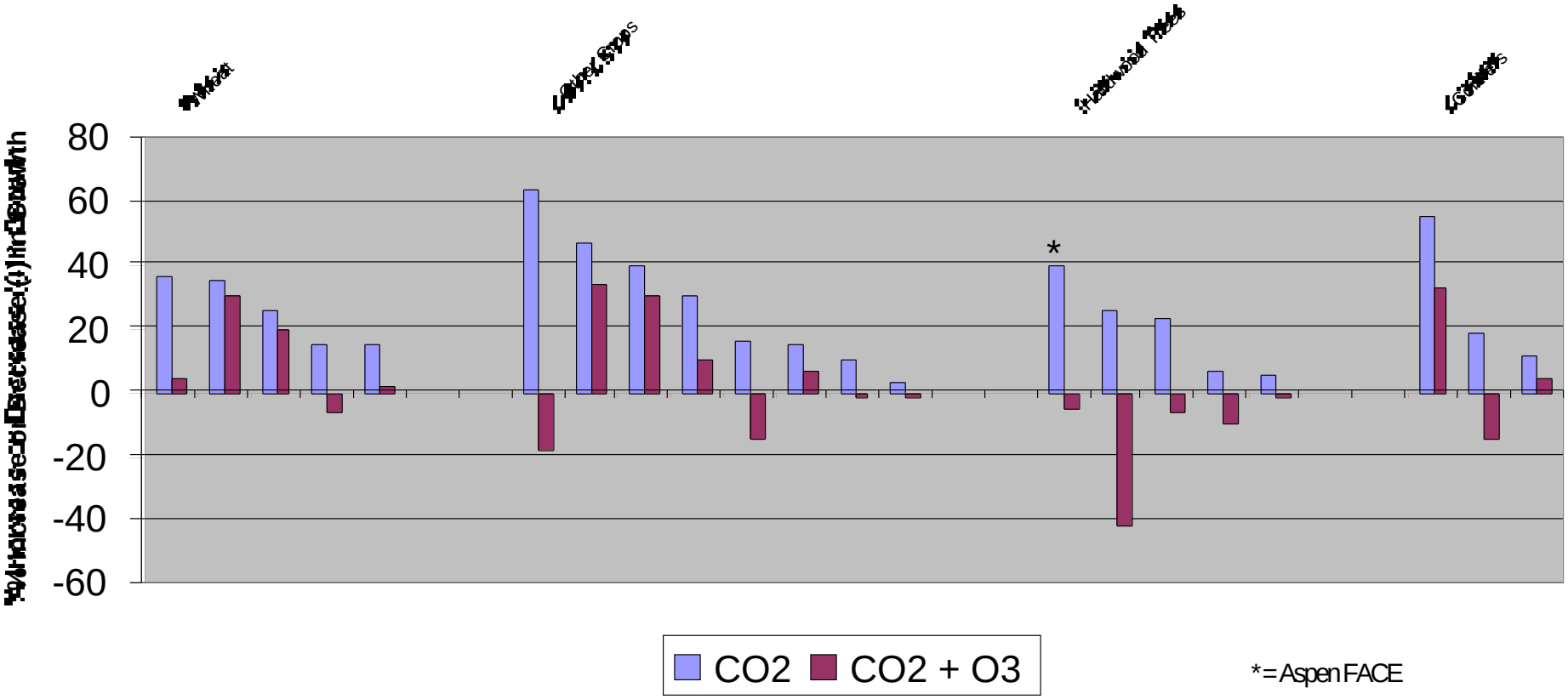
Relative effect of controlled exposure to elevated CO_2 (enriched to 500-700 ppm) or elevated CO_2 plus ozone compared to ambient controls



Moderation of the Response to Elevated CO_2: Ozone

Short-term Research Needs

- Compare open-top chamber and FACE results.
- Evaluate dose responses of CO_2 and O_3 concurrently for key agricultural and forest species
- Examine mechanisms of CO_2/O_3 interactions.
  - Gas exchange dynamics
  - Role of antioxidant up or down regulation
- Site water balance
  - CO_2 and O_3 suppress stomatal conductance and alter leaf area
  - Stand level water balance for key agricultural crops and forest trees under CO_2+O_3?
- Impacts of CO_2/O_3 on phenology of northern temperate crops and trees.

Moderation of the Response to Elevated CO_2: Ozone

Long-term Research Needs

- Compare CO_2/O_3 impacts on stand level crop and forest situations (WUE, LAI, NPP, Soil C, etc.)

- Examine CO_2/O_3 impacts on ecosystem-level responses (nutrient cycling, water balance, trophic interactions, soil microorganisms, etc.).

- Determine how CO_2/O_3 affect biodiversity of plants, insects, and soil fauna and microbial communities.

- Examine how CO_2/O_3 affect interactions with other environmental stresses (warming, drought, competition, pests, N additions, etc.).

ACKNOWLEDGMENTS

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